MANUAL OF FRACTURES

TREATMENT BY EXTERNAL SKELETAL FIXATION

By

C. M SHAAR, M D , F A C S
Captain, Medical Corps United States Navy

and

FRANK P KREUZ, JR , M D , F A C S
Lieutenant Commander, Medical Corps, United States Navy

ILLUSTRATED

W. B. SAUNDERS COMPANY
PHILADELPHIA AND LONDON
1943

Reprinted June 1944

MADE IN U. S. A.

PRESS OF
W. B. SAUNDERS COMPANY
PHILADELPHIA

DEDICATED

To

The memory of the United States naval medical officers and hospital corpsmen who have lost their lives in the service of their country

FOREWORD

It is with real pleasure that I write a brief word of introduction to this manual on fracture treatment

The violence of present-day warfare presents dozens of problems to the surgeon who must handle bone injuries Through the years there has been great discussion as to the best methods of handling fractures of all types Today there is much the same keen interest, and it is to be hoped that before this war is over many of these questions will have been settled

The subject "External Skeletal Fixation," which is the subtitle of this volume, is a particularly pertinent and vital one to the naval surgeon The motion of a ship at sea, the necessity of precipitate evacuation of wounded and their handling in small boats, are factors which militate against traction and suspension in fracture treatment All steps toward more efficient technique in the integral fixation of long bones and the mandible are to be encouraged

I take this opportunity of expressing my personal pride in this timely and well written manual by Captain C M Shaar, Medical Corps, U S N, and Lieutenant Commander Frank P Kreuz Jr, Medical Corps, U S.N It is a real contribution and much good should come from it

Ross T McIntire

Rear Admiral, Medical Corps, U.S N
The Surgeon General of the Navy

PREFACE

The title of this book is not intended to convey the impression that the first or most important method of treating fractures is external fixation to the exclusion of other methods The book has been written to meet the current need for the treatment of fractures where other methods are not practicable In this way the constant endeavor has been to present a handbook for the surgeon and a guide for the beginner interested in the field of external fixation

The fundamental principles of treating fractures are reduction, retention in proper position, and restoration of function The accepted methods for the treatment of fractures are fixation in a plaster cast, skeletal traction internal fixation and external fixation Good results with any method will depend upon accurate knowledge of the normal and the pathologic anatomy of fractures, a clear understanding of the fundamental principles involved, and upon the ability of the surgeon—not merely on the use of certain methods or appliances

Although the plaster cast is ideal in certain selected cases and for fractures that are easily reduced and retained in proper position, skeletal traction is essential in the treatment of certain groups of cases Its use at sea, however, has been seriously handicapped by the pendulum motion (of the traction and countertraction weights) which is caused by the rolling and pitching of the ship An antipendulum fracture frame was designed by one of us in 1929 to overcome this handicap and one chapter in our manual is devoted to a description of this method While this method is very useful in peacetime, it is not practical in time of war If a naval battle is impending or in progress, the patient may be forced to disentangle himself from the lines, weights and pulleys The plaster cast applied to a lower extremity presents serious handicaps at sea If applied aboard ship, or on the extremity of a patient who will have to be transported across the sea, the cast will become an anchor if the patient suddenly has to abandon ship

Internal fixation likewise has certain important indications and is practicable at base hospitals, but not at sea in time of war or in hospitals where teamwork, organization and control of asepsis and antisepsis are imperfect

External fixation, however, is ideal for use at sea and in mobile hospitals where transportation of patients becomes necessary In selected cases it has proved its special merit in some of our base hospitals Of the various methods of external fixation, we prefer the Stader reduction and fixation splint If the correct technique is used with meticulous attention to detail, the results will be most satisfactory Incorrect anatomical principles and faulty technique will of course yield poor results

In the following chapters a detailed description of the methods we have been using for the past two years will be given A chapter is included on roentgenographic study of bone reaction and changes around pin holes and fracture sites by Lieutenant Commander Stephen L Casper, MC V(S), U S N R, and there is a chapter on the method and type of anesthesia we employ in the reduction of fractures by Lieutenant Commander Donald E Hale, MC-V(S), U S N R

We cannot too deeply express our appreciation and gratitude to our assistants, especially Lieutenant Donald T Jones, MC-V(S), U S N R, for their help and cooperation and for their splendid work in treating a large number of fractures by this method, and to Commander J S Barr MC-V(S) U S N R, for his constructive criticisms in reviewing the text We are grateful also to Commander George U Pillmore, MC-V(S), U S N R, for his assistance in the preparation of the x ray pictures presented in this manual, and to Willard Maginnis, Pharmacist's Mate 3/c, U S N R, hospital photographer, Thelma Barringer, for some illustrations and Lucile Childs, for secretarial help

We wish also to express our thanks to the publishers for their helpful courtesy and cooperation in the production of this work

C M Shaar,
Frank P Kreuz

CONTENTS

SECTION I

EXTERNAL SKELETAL FIXATION—GENERAL CONSIDERATIONS

SECTION III

DELAYED UNION AND NONUNION

CHAPTER VIII

SECTION IV

SPECIAL FRACTURES

CHAPTER IX

CHAPTER X

CHAPTER XI

CHAPTER XII

CHAPTER XIII

CHAPTER XIV

CHAPTER XV

SECTION V

COMPLICATIONS IN FRACTURES

CHAPTER XVI

SECTION VI

ARTHRODESIS OF JOINTS

CHAPTER XX

SECTION VII

BONE GRAFTS

CHAPTER XXI

SECTION VIII

INCIDENCE OF FRACTURES IN THE SERVICE

CHAPTER XXII

SECTION IX

ANESTHESIA X RAY STUDY

CHAPTER XXIII

CHAPTER XXIV

APPENDIX

CHAPTER XXV

SECTION I

EXTERNAL SKELETAL FIXATION—GENERAL CONSIDERATIONS

CHAPTER I

INTRODUCTION AND OBJECTIVES OF TREATMENT

In the treatment of fractures, the fundamental principles of *accurate reduction, rigid uninterrupted fixation,* and *early restoration of function* are the bases of good results It is not sufficient to know that the fracture is simple or compound, transverse or oblique, spiral or greenstick, impacted or comminuted, or whether it enters the joint In addition, an accurate appraisal of injury to soft tissues, especially the blood vessels and nerves, is imperative The importance of x-ray examinations before and after reduction and during the period of follow up, and the selection of the proper type of anesthesia for reduction cannot be overemphasized

Fractures, whether in civilian life or military service, are not infrequently associated with other injuries The primary *objective in treatment is therefore first to save life, then limb,* and finally to restore the limb to normal or useful function *The initial effort should be directed toward controlling the shock* and *hemorrhage* which are present in all major fractures Various degrees of burns may also complicate the fracture, especially in the military services It is in this combination of injuries that external fixation becomes the ideal method While the proper treatment of the fracture is being applied, the treatment of the burn will not be interfered with

In the military service, it is not only the best method of treatment that must be considered, but one that permits

treatment of a large number of casualties in a limited time. A satisfactory method is one that is simple to apply, gives rigid fixation, allows the patient to become ambulatory in days instead of months, facilitates transportation of the patient, requires a minimum amount of nursing care, is reasonably comfortable, and permits immediate active motion without fixation of the adjacent joints. External fixation is the method of choice when it becomes necessary to transport fracture casualties over long distances whether on the field or at sea. The Stader splint seems to fulfill these requirements very satisfactorily.

External fixation is neither a substitute for, nor a short-cut to the science of fracture treatment. As in the case of any other method, the successful approach to the management of fractures by external fixation will depend upon the surgeon's knowledge of the anatomic, physiologic and pathologic aspects of fractures as well as his mechanical ability.

Because the treatment of fractures is essentially a mechanical problem, the surgeon must possess a thorough knowledge of the stresses and strains that must be overcome and maintained to reduce fractures effectively, and to hold this reduction until solid bony union has occurred. The Stader splint will greatly facilitate the solution of these mechanical problems. Its usefulness may be increased by the ingenuity and skill of the surgeon.

CHAPTER II

HISTORICAL APPROACH

In 1897 Clayton Parkhill, an American surgeon, inserted screws from cortex to cortex and then connected the screws with an external clamp in treating difficult fractures of the femur This apparatus became known as the Parkhill bone clamp He was the first surgeon to recommend and employ rigid external fixation in the treatment of fractures of the long bones

It was not until 1904 that Codivilla employed the principle of pins in leg-lengthening operations These he connected with external bars without the use of plaster After the advent of the Steinmann pin, various interpretations of its adaptation, especially with regard to external fixation of the pins with plaster or mechanical devices, were published by many The literature pertaining to the use of the pins or screws inserted into bone fragments above and below the fracture for the purpose of external fragment reduction control and subsequent fixation, is so voluminous (*see supplementary Bibliography*) that it may be well to discuss briefly, in general the various methods so that the student of fracture treatment can visualize more clearly the evolution of the advancements that have taken place

Until the principles of the Steinmann pin were described by Codivilla in 1904, the treatment of fractures meant the use of plaster of paris or various methods of external traction and countertraction

With the advent of skeletal traction, popularized by Steinmann, the next noteworthy advance was the incorporation of the Steinmann pins or Kirschner wires in plaster for the so called transfixation of the fragments Böhler's contribution during this phase was outstanding His use of a simple reduction frame and screw traction apparatus, in conjunction with pins or wire, introduced a new era in accepted

fracture treatment His persistent efforts and successes were chiefly responsible for the gradual elimination of pin phobia held then by many surgeons and still retained by some today His simple reduction frame is the basis for many of the elaborate devices now offered the traumatic surgeon

In 1919 Freeman published an article advocating the use of external fixation in the treatment of fractures He pointed out and emphasized the advantages of this method Lamare described half pins placed at an angle to each other which were similar in principle to those used by Schantz and later by Riedel in femoral osteotomies, and used successfully in this country by Anderson in treating fractures of the femur

During the period of transfixation of fractures to eliminate the necessity of continuous traction, efforts were also being made to eliminate the necessity for the use of plaster itself

Although Codivilla and others bridged Steinmann pins with external metal bars, the method never became popular because of the through-and-through pinning required Lamare, in a description of angular pins placed through the outer and inner cortices only, which he bridged in units by means of metal bars, opened the approach to an external mechanical method of treating fractures, which could be applied to one aspect of the limb only, thereby eliminating the objectionable through and through pinning, and plaster

Recognizing the greater necessity for the elimination of plaster in the treatment of fractures in dogs, because of plaster soilage, cast destruction by the animal, and the difficulty of applying plaster and maintaining immobilization, as well as the too often occurring gangrenous sequelae, Stader developed a unique device for the treatment of fractures, in which he combined mechanical reduction and subsequent immobilization in a single compact unit

Stader first presented the advantages of his splint to us in December, 1941 Since that time we have used it in over 157 cases of various types of fractures and orthopedic problems We realize that this small number of cases and

the short time interval do not speak for a final evaluation of the method employed, but we feel that the present war emergency requires one to bring before the medical profession and the armed services, as quickly as possible any method of merit for caring for the injured

CHAPTER III

SHOCK IN FRACTURES

In combat zones there are many factors that predispose to and aggravate shock—factors that are seldom seen in peacetime Fear, anxiety, exposure to cold or heat dehydration, overexertion, hunger, long hours of duty, and lack of rest are important contributing factors in war Not infrequently, one sees a man only slightly wounded in battle who is suffering from shock In the light of these facts it is important for the medical personnel to be able not only to recognize shock, but to recognize it in its impending and early stages Laboratory methods are not available on the battlefield and there and aboard ship in time of action diagnoses should be made on the clinical findings only, any change from the normal that becomes progressively worse should be a sufficient warning of impending danger

Shock in major fractures is early and profound Loss of fluids in compound fractures is continuous and in all but the mild cases the administration of at least two pints of plasma is indicated The earlier it is given, the more effective the results will be In severe cases larger quantities of plasma are required and the continuation of its administration is necessary until the shock is overcome

In the first World War the death rate in major compound fractures especially of the femur, was appalling The mortality was not reduced until the introduction of the Thomas splint, which made possible the immediate immobilization of fractures This decreased the mortality to such a low level that the well known slogan of "splint them where they lie" became popular among all physicians This emphasizes the importance of immediate immobilization as an adjunct to the administration of plasma and morphine in combating shock

It is needless to emphasize the necessity of immediate control of hemorrhage and the administration of a sufficient amount of morphine to completely relieve pain

CHAPTER IV

PRINCIPLES OF THE STADER REDUCTION AND FIXATION SPLINT

The Stader reduction and fixation splint requires no extension apparatus no special frame or fracture table and no plaster cast It is a self-contained reduction and fixation unit for fractures complete in itself The splint consists of a half pin unit placed in the proximal fragment and a second half pin unit in the distal fragment An adjustable connecting bar assembly joins the two half pin units to each other and bridges the fracture By activating the turnbuckle in one direction the fragments are distracted By activating it in the opposite direction the fragments are apposed Reduction maneuvers are performed by activating certain screws

ADVANTAGES OF THE STADER SPLINT

The outstanding advantages of the Stader reduction splint are the simplicity of the reduction maneuvers coupled with its compactness its relatively light weight and the fact that it is applicable to one aspect of the fractured limb only The fact that the adjustable connecting bar assembly remains after reduction and then acts as the splint has the further advantage of enabling one to make any desired adjustments at the bedside without removing the patient to a special bulky reduction frame This advantage is of special value for example in leg lengthening operations and other operative procedures met with in bone surgery

With the Stader splint, therefore it is entirely feasible and may often be desirable aboard ship and in field hospitals to apply the splint as a reduction and immobilizing agent. If secondary adjustments are necessary, they may be performed later in a base hospital under fluoroscopic control without subjecting the patient to any further surgical procedures

We subscribe fully to Bradford's statement wherein he points out the shortcomings of definite skeletal fixation He states "Any form of treatment that tends to fix fracture ends in a position of distraction, cannot fail to delay and prevent union since the pins allow no backward slipping and their position is locked in place Mechanical fixation should become a treatment of persistent controlled impaction which offers an advantage over any other method available except those suitable for walking casts Lambotte anticipated this principle over forty years ago"

Bohler's success with walking calipers in tibial fractures is due chiefly to the continuous impaction of the fragments obtained Similarly, the impacting adjustability of the Stader splint, without fragment disalignment, is a distinct advantage

The complete articular freedom above and below the fracture afforded by the Stader splint decreases to a minimum the joint disabilities so often observed where joints have been immobilized over long periods of time The active motion possible enhances circulation, reduces soft tissue atrophy, favors early union, adds greatly to the patient's comfort and in most instances renders the patient ambulatory from the first postoperative day This last mentioned advantage is of special significance in wartime, as it permits evacuation of patients from danger zones, either by themselves or with a minimum of assistance

CHAPTER V

PIN SEEPAGE

The most serious objection to external fixation is the possibility of infection from the use of pins We have had no *infections from pins in 157 consecutive cases* One must however, differentiate between ordinary pin seepage and actual infection about the pin sites A small amount of seepage occurs in about 10 per cent of cases and those accustomed to the use of pins and wires for traction and transfixation in the treatment of fractures will have no difficulty in evaluating the significance of the drainage about the pins in every case The inexperienced however will tend to view with undue alarm even the slightest drainage and encrustation and may remove the pins prematurely Premature disruption of fixation may cause serious complications especially in compound fractures where uninterrupted immobilization is essential

A certain amount of pin seepage must be accepted as a necessary evil whenever pins or wires are used but its incidence can be limited to a negligible factor if necessary precautions are used

THE CAUSES OF PIN SEEPAGE

1 Movement of the Skin about the Pins

Whenever pins are inserted in locations where motion exists between the skin and the pins the incidence of pin drainage will be increased, e g near joints where skin motion is excessive The skin wound produced by penetration of a pin through it cannot heal under the irritating effect of constant movement and will therefore produce a discharge The elective sites for insertion of pins adjacent to joints must therefore correspond to those areas where undue skin motion does not occur

2 Skin Tension

Abnormal skin tension or pressure about the pins causes necrosis of the surrounding skin with its resultant discharge The most important factors producing skin tension are

a *Improper drilling of the pins*
The angular direction of the pin insertions tends to slide the skin in the direction of the pin and thus cause a "puckering" of the skin This can be prevented by directing the pin transversely through the skin to the bone before drilling into the bone Sliding the pin along the longitudinal axis of the bone must also be avoided as it carries all the soft tissues with it and produces abnormal tension of the skin and soft tissues

b *Failure to allow for skin tension produced by traction*
Before the second pin unit is applied, the operator must always "relax the skin" between the pins, so that when traction is applied there will be no skin tension This principle must also be taken into consideration during the insertion of the second pin of each pin unit In the case of fractures of the os calcis for instance, a pin is inserted into the os calcis first and manual traction is applied by grasping the U shaped bar so as to stretch the skin before inserting the tibial pins These simple precautions will greatly decrease the incidence of pin seepage resulting from skin tension

3 Loose Pins

a The most important single factor causing a loose pin is *the improper seating of the pins* Pins that do not penetrate both cortices will always be loose, thereby defeating the mechanical principles of external fixation itself as well as producing pin seepage It must be repeated over and over again that *external fixation will fail if the pins do not penetrate both cortices*

b Unsteady or improper drilling of the pins into the bone produces a channel larger than the pin itself and predisposes to loosening of the pins and pin seepage

c. Pins should never be inserted into markedly demineralized or soft cancellous bone because they will not hold unless supported by a plaster cast. When left unsupported, such pins will quickly loosen and cause seepage and instability of the splint.

4. Insertion of Pins in the Fracture Hematoma

It is not always possible to determine the size of the fracture hematoma, which in many cases may extend a great distance along the shaft. When pins penetrate the hematoma an external exit is produced, and during the leukocytic stage of tissue repair the discharge may be confused with actual suppuration. One should, therefore, always insert the pins as far away from the site of the fracture as possible.

5. Insertion of Pins Through Traumatized or Devitalized Soft Tissues

Whenever pins are inserted through traumatized or devitalized soft tissues, the incidence of pin seepage is increased, and the discharge usually subsides as the stage of repair progresses. Unless pins are inserted through normal tissue, external fixation is usually contraindicated as it predisposes to infection.

6. Local Irritating Factors

a. Constant irritation of the skin about the pin sites by topical application of antiseptics or by various bulky dressings tends to prevent healing of the traumatized skin and increases the pin seepage. Wet dressings should also be avoided. It is best to keep the pin sites as well as the corresponding pin bars dry. They may be protected by dry sterile dressings when necessary. The dry crust which forms about the pins is nature's protective wall and should not be removed.

b. Failure to properly remove the hair about the pin sites may cause the hair to be forced into the pin sites during the drilling and thus act as a foreign body.

c. Failure to clean pin of any irritating material after

its emergence from the pin bar, and prior to skin penetration, may result in the forcing of this material into the wound

7 Thermal Necrosis

Too rapid drilling of a sharp pin, or prolonged drilling of a dull pin will result in thermal injury to bone and soft tissue The effect of this thermal injury manifests itself clinically in excessive seepage and in some cases in the formation of a "ring" bone sequestrum The use of an electric drill is contraindicated for this reason The flexible shaft hand operated drill has proved to be ideal for pin insertion

8 Electrolysis

There is evidence to support the belief that whenever pins are connected by a metal of different electrical potential, a current is generated which tends to increase the incidence of pin seepage When a nonmetallic pin bar is used, the electric current does not pass from one set of pins to the other, and the incidence of pin seepage is greatly reduced A more detailed study of this phase of seepage appears in Chapter XXIV

SECTION II

THE STADER SPLINT

CHAPTER VI

MECHANICAL PRINCIPLES AND METHOD OF APPLICATION

To familiarize the reader with the mechanical principles and method of application of the Stader splint, we have selected fractures of the tibia for the presentation This selection was made for two reasons, namely, the ease of the application of the Stader splint in this fracture and the frequency of the fracture—factors which combine to cause the splint to be used more frequently on the tibia than on any other bone

MECHANICAL PRINCIPLES

The splint consists of two half-pin units, one placed in the proximal fragment and the other in the distal fragment (Figs 1, 2, 3, 4) The half-pin units are joined by the adjustable connecting bar assembly (Fig 2, *Z*) which bridges the fracture On either end of the connecting bar assembly is the mechanical reduction unit consisting of (1) a stud bolt (Figs 2, 3, *D*) which connects the mechanism to the pin bar; (2) a pair of adjustable screws (Figs 2, 3, 4, *F*) which activate the pin bar and fragment in one plane, (3) a second pair of adjusting screws (Figs 2, 3, 4 *G*) at right angles to the first pair which activate the pin bar and fragment in the opposite plane

In this manner, both proximal and distal fragments are mechanically controlled in each plane (Fig 7) By activating the turnbuckle (Figs 2, 3, 4, *H*) in one direction the fragments are distracted By activating it in the opposite

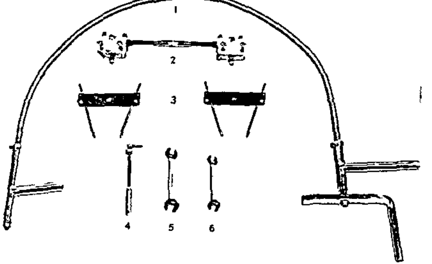


Fig 1—Splint and instruments necessary for its application *1*, Flexible shaft drill *2*, Adjustable connecting bar assembly. *3*, Pin units *4*, Universal wrench for locking pins into pin bar *5* and *6*, Wrenches for locking of nuts and activating bar and screws

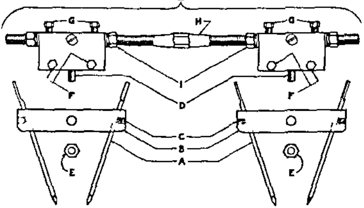
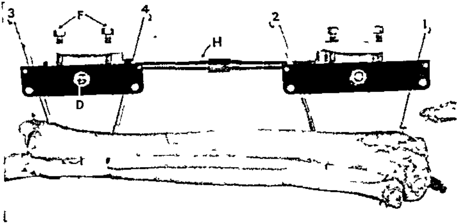
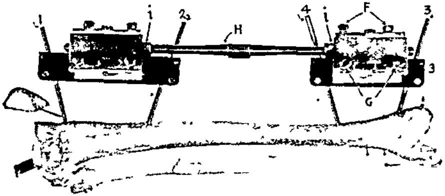


Fig 2.—Schematic drawings of Stader reduction splint. *A*, Stainless steel pins *B*, Pin blocks *C*, Set screw locking pins. *D*, Hinge bolt. *E*, Nut attaching pin block to hinge bolt. *F*, Mediolateral adjusting screws *G*, Anteroposterior adjusting screws *H*, Adjustable connecting bar *I*, Lock nuts locking bar *H*. *Z*, Adjustable connecting bar assembly

direction, the fragments are apposed. The lock nuts (Figs 2, 3, 4, *I*) lock the turnbuckle and prevents rotation of the fragments.





Figs 3 and 4.—The Stader splint viewed from both sides, showing mechanical application to tibia. Pins numbered *1*, *2*, *3*, *4* in order of their insertion into the bone *D*, Bolt connecting half-pin unit to adjusting mechanism. *F*, Adjusting screws which control pin bar and fragment in opposite plane. *H*, Turnbuckle. *I*, Lock nut to secure turnbuckle to adjusting mechanism.

METHOD OF APPLICATION

The pins are designated as *1*, *2*, *3*, and *4*, according to the sequence of their insertions. The proximal pin unit is applied first, in the following manner: The first pin is passed

through the hole in the pin bar (Fig 5) and inserted directly through the skin to the bone about one fingerbreadth below the knee joint After the pin is firmly seated, the pin bar must be held parallel with the long axis of the proximal fragment (Fig 5) during the drilling of the pin through the bone The pins must always penetrate both cortices If this important fundamental rule of pin insertion is not adhered to, firm fixation of the pin unit to the fragment will not be accomplished

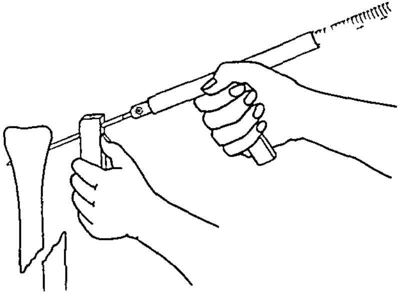


Fig 5—The first pin is inserted with flexible shaft drill Pin bar held parallel to the proximal fragment.

The pins should be drilled as follows

1 Employ a hand-operated drill with a flexible shaft (Fig 8) The use of electrically driven drills is contraindicated (see Chapter XXIV)

2 Exert firm steady pressure This is best accomplished by resting the elbow on the chest during the act of drilling

3 Drill through outer cortex and medullary canal to the inner cortex before stopping

4 The operator now knows that only ¼ to ⅜ inch of fur-

ther drilling is necessary for the pin to penetrate the opposite cortex. As the pin emerges through the opposite cortex, a definite diminishing resistance is easily felt.

The second pin is inserted in similar fashion, but before drilling make certain that the pin bar is held parallel to the long axis of the proximal fragment and at least one fingerbreadth from the skin (Fig. 5), to allow for swelling that may ensue.

The two pins are now locked in the pin bar by tightening the set screws (Fig. 6). Before applying the distal half-pin

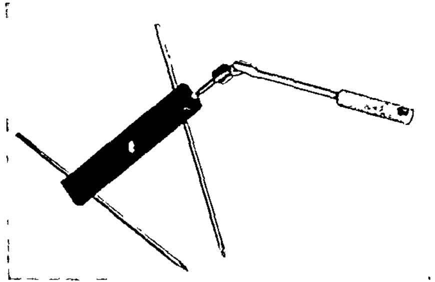


Fig. 6—Universal wrench for locking pins into pin bar.

unit, the rotational deformity of the distal fragment should be corrected by hand. While held in this position, the third pin (the one nearest the ankle joint) is drilled about one fingerbreadth above the ankle joint, care being taken to observe the same rules detailed for the upper pin unit. The fourth pin is then drilled in like manner. If the pin units have been properly placed they will assume parallel alignment to each other. Before the connecting bar assembly is attached, all of the various adjusting screws should be unscrewed to their maximum limits.

The major displacement of the fragments is now reduced by hand manipulation of the pin bars With the pin bars held in the desired position the connecting bar assembly is attached and all adjusting screws are tightened by hand only Any remaining obvious deformities may now be corrected by manipulating the proper adjusting mechanism As a final procedure all adjusting screws and nuts are tightened firmly with the aid of wrenches

X ray examinations may be made immediately, or at the first opportunity Accurate reduction of the fragments can be obtained under fluoroscopic guidance but the operator

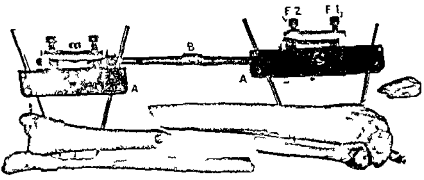


Fig 7—To correct the above displacement loosen adjusting screw *F 1* and screw down *F 2* *A* Pin unit *B* Turnbuckle

must keep in mind the dangers to himself from overexposure to x ray especially if he is called upon to treat a large number of fractures in a short period of time Usually routine x ray pictures are a sufficient guide to complete the reduction

As a general rule it is best to obtain complete reduction at the first operation while the patient is still under the initial anesthesia It may become necessary in certain selected cases to delay complete reduction until a later date The condition of the patient excessive swelling and damage to soft tissue and marked overriding of fragments are influencing factors In cases of overriding with excessive

swelling it is best to postpone turnbuckle traction until the danger has passed In the treatment of a large number of fracture cases it is best to apply the splint as an immobilizing agent after maximum reduction has been obtained by hand manipulation and postpone the fine adjustments for a later date This will enable the surgeon to treat a large num

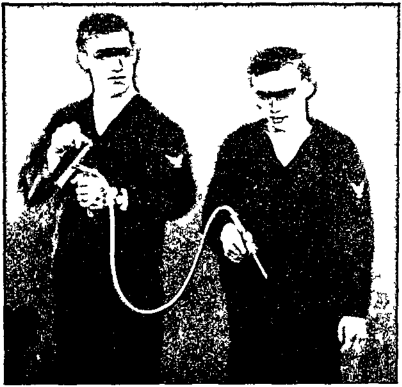


Fig 8.—Hand-operated bone drill for insertion of pins The use *of an electrically driven drill is contra nd cated because of the re sulting thermal reactions in bone*

ber of casualties in a short period of time Frequent manipulation of the fragments should be avoided since it predisposes to delayed union In compound fractures the frequent interruption of rigid fixation may lead to infection

It is usually desirable and feasible to obtain anatomical reduction with the aid of the adjusting mechanism of the splint The beginner, however should concentrate first on

accuracy in the pin insertions, and employ hand reduction of the fracture The proper technique for finer adjustments is gained only by experience and accurate knowledge of the mechanics of the splint

Reduction of fractures by external skeletal fixation requires a careful diagnosis of the *planes of the fracture lines* When these planes are known and visualized, mechanical adjustment of the fragments is greatly simplified In transverse fractures, for instance, the shortening or overriding must be reduced before the laterally displaced fragments can be properly apposed In spiral oblique fractures, the irregular wavy surfaces of the fracture require appropriate traction as well as derotation before the fragments can be brought together The fragments usually slip in place without force when the proper reduction maneuvers are executed unless soft tissue is interposed between the fractured surfaces In such cases, it may become necessary to remove the interposed tissue surgically

If the operator encounters difficulty in the reduction of spiral fractures, it is advisable to remove the connecting bar assembly, apply traction for a period of fifteen to thirty minutes reapply the assembly bar, and complete the reduction maneuvers When however, in such cases extension is being applied by means of the turnbuckle, all adjusting screws and the lock nut of the turnbuckle should be completely loosened This permits free skeletal manipulation without mechanical interference and allows correction of rotation by hand

STADER SPLINT

See pages 260 to 265

CHAPTER VII

ERRORS IN THE TREATMENT BY EXTERNAL SKELETAL FIXATION

It is important to have a clear understanding of the mechanics of this splint and its proper application Any deviation from the principles set forth will usually give unsatisfactory results The errors to be pointed out and emphasized are errors committed by the inexperienced, not only in the use of the Stader splint, but in the use of any type of external skeletal fixation apparatus

It is as important to point out the errors and pitfalls in surgical procedures, as it is important to show the rocks and shoals on a navigator's chart before the beginning of a journey

Treatment of fractures by external skeletal fixation is not new, yet this method has not gained the popularity it deserves Lack of a proper appliance and the commission of errors in the application of the method have been largely responsible for its unpopularity

ERRORS

1 *Improper selection of cases* External skeletal fixation is not indicated in all fractures
2 *Failure to take x-ray pictures* before and after reduction and during the period of follow-up
3 *Improper and inadequate anesthesia* Proper relaxation is necessary, as in any other method Special types of anesthesia are indicated in certain fractures
4 *Errors in selection of proper sized splint and pin assemblies* A tibial splint is not strong enough for a fractured femur, and a humeral splint will not be adequate for the tibia The pins must also be of sufficient diameter and length The proper sized pins will fit snugly in the proper pin bars The entire splint assem

bly and accessories should be examined and laid out before operation

5 *Errors in splint placement* In order to insure the mechanical benefits of external skeletal fixation the splint should be applied to the proper aspect of the limb The double pin units must always be placed as close to the extremity of the bone as the anatomical structures permit to obtain the necessary leverage for reduction maneuvers as well as to give stability to the splint

6 *Errors in Pin Insertion*

a Failure to penetrate both cortices The pins must always penetrate both cortices If they do not the fragment will not be held the splint will be unstable and the pins will become loose

b Insertion of pins into markedly demineralized or cancellous bone

c. Insertion of pins through devitalized or infected soft tissues

d Insertion of pins through important anatomical structures, e g joints tendons

e Too rapid or unsteady drilling of the pins Rapid drilling causes thermal necrosis Unsteady interrupted and jerky drilling unduly traumatizes the bone and leaves a channel too large for a firm pin anchorage Steady firm and constant pressure must be exerted on a slowly revolving pin to overcome these hazards

f Failure to pull skin toward fracture when inserting pin in order to prevent tension when traction is applied If tension is evident after the necessary traction has been applied a longitudinal incision in the skin should be made near the pin Excessive tension on the skin interferes with reduction maneuvers and causes ischemic necrosis of the skin

g Preliminary drilling for pins should not be undertaken Drilling should be made by pins which when once inserted should remain in place

7 *Errors in Reduction*

a Failure to secure alignment of extremity before insertion of half pin unit

b Failure to obtain all possible reduction by hand manipulation before attaching the connecting bar assembly After manipulative reduction the rest of the reduction to anatomical position may be made by the apparatus

c Forceful and rapid traction will result in injury to soft tissues and may interfere with the circulation and impair the blood supply especially in the presence of excessive swelling

d Too strong impaction causes tissue necrosis and may result in bowing—anterior posterior lateral or medial

e Failure to approximate properly Distraction results in delayed union and nonunion

f Failure to use straight traction on the extremity before the application of the splint especially in spiral fractures

g Failure to flex the extremity during manual reduction prior to the application of the splint

h Failure to compare the injured with the uninjured extremity during and after reduction maneuvers Obvious deformities are easily seen and corrected by such an examination

i If satisfactory reduction and alignment are not obtained in a reasonably short time the failure is *usually the result of soft tissue interposition between fragments* Open reduction should be undertaken to free fragments from soft tissue after which external fixation is reapplied This should be completed prior to the tenth day from the time of injury Further delay beyond this period of time may result in delayed union

8 *Failure to institute proper postoperative care* as regards motion of joints weight bearing care of pin sites and treatment of the general condition of patient

9 *Failure to keep accurate records of each case* so that

errors may be identified, and correct measures taken to combat them

10 *External skeletal fixation is contraindicated in the treatment of fractures in children* Possible injury to the epiphysis and the amenability of children to treatment by conservative methods are sufficient reasons to contraindicate its use It may be used to advantage, however, in selected reconstruction operations in children

SECTION III

DELAYED UNION AND NONUNION

CHAPTER VIII

DELAYED UNION AND NONUNION

THE PROCESS OF FRACTURE HEALING

In every fracture there is injury to the adjacent soft parts The extravasation of blood and tissue fluids from these soft tissues in and about the fracture site makes up the fracture hematoma The primary reaction to the trauma is one of inflammation Many inflammatory cells chiefly polymorphonuclear leukocytes and large mononuclear phagocytes, are present in the early stages of repair Resorption of the bone ends and devitalized bone occurs, and a fibrin clot is deposited Connective tissue cells invade this clot to form granulation tissue An intercellular matrix is now formed between the connective tissue cells The appearance of this osteoid matrix is the first evidence of bone formation Osteoblasts now appear to form the canaliculi of the bone matrix These canaliculi serve as a medium of transfer of the metabolites from the bone cells to the blood The osteoblasts aid in the formation of new bone matrix and trabeculae Finally, calcium is deposited in the matrix, to form adult bone The actual process by which calcium is deposited in the matrix is unknown

Complete repair of bone, therefore, requires both the formation of the bone matrix and the calcification of the matrix Without proper calcification a fibrous union results There is evidence to support the view that the enzyme phosphatase is secreted by the fibroblasts, and that the available calcium is derived both from the blood and from the adjacent bone ends as a result of the resorptive processes

Adult bone is constantly undergoing active metabolism. In young bone, the regenerative processes are greater than the degenerative. As age proceeds, the degenerative processes become more prominent. To sustain this metabolism, the bone obtains certain necessary chemical, hormonal and enzymatic elements from the blood. An adequate blood supply is therefore essential. Activity of the muscles and joints is the best method of promoting adequate circulation of the extremity, and is especially indicated in older patients. Retardation of calcium deposition in the matrix is chiefly due to inactivity and immobilization of the joints adjacent to the fracture, and not to a lack of calcium in the blood.

The metabolic activity at the fracture site is often extensive, and may account for the marked resorption of the ends of the fragments so frequently seen during the process of bone repair.

Osteogenesis is stimulated mainly by the stresses and strains of the bone ends in the direction of their lines of force. This is borne out clinically by the good results obtained in fractures of the tibia by means of properly applied external skeletal fixation or a walking cast, in spite of the fact that delayed union and nonunion are more common in fractures of this bone, especially in the lower third, than of any other.

Absolute uninterrupted immobilization of the fractured ends is required as soon as the osteoid matrix has been laid down. Torsion and twisting motion of the fracture site interferes with this healing process and predisposes to delayed union and nonunion. Frequent interruption of fixation, overextension, and a period of fixation that is too short all tend to produce delayed union and nonunion.

Active motion of all the joints of the extremity that do not require immobilization will avoid many of the problems associated with the healing of fractures. Muscle and joint activity prevents atrophy and demineralization and provides the necessary circulation for the proper reparative processes, especially the deposition of calcium in the bone matrix.

Osteoblasts are also probably stimulated by the sex hor-

mones. Early preponderant degenerative changes of bone are *often associated with a deficiency of the sex hormones.* It is characterized by osteoporosis and thinning of the cortex. These changes occur in both sexes. In the male it is spoken of as senile osteoporosis, in the female, postmenopausal osteoporosis.

THE CAUSES OF DELAYED UNION AND NONUNION

General Causes

Senility
- Deficiency in sex hormones
- Deficiency in circulation

Diet
- Deficiency in protein intake

Diseases
- Osteomalacia, rickets, gumma, tabes dorsalis, carcinoma, etc

Local Causes

Deficient reduction
- Improper apposition of the fragments
- Interposition of soft parts
- Excessive traction
- Mechanical distraction of the fragments

Deficient fixation
- Fixation for too short a time
- *Frequent interruption of immobilization*
- Nonrigid fixation
- *Fixation of adjacent joints*

Deficient functional restoration
- Failure to actively move all joints not requiring immobilization
- Active motion of the adjacent joints prevents atrophy and demineralization and insures the necessary blood supply to the extremity for the proper deposition of calcium in the matrix as well as a better healing of the fracture

Local disease processes
- Osteomyelitis, carcinoma, gumma, etc

Prolonged and extensive immobilization in plaster casts
- This causes atrophy and osteoporosis, and delays healing

Because the reparative phase of metabolism (anabolism) is chiefly concerned with protein, an adequate protein intake is necessary for proper repair of fractures. An adequate nitrogen balance should therefore be sought after in the treatment of serious wounds and injuries. Hypoproteinemia should be guarded against during the healing of fractures Where adequate proteins cannot be administered by mouth,

intravenous plasma may be given The influence of vitamins on bone repair is not well understood, but the administration of vitamins to sustain normal health should not be neglected It is not the lack of calcium, phosphorus and other inorganic substances in the blood that causes the delayed union and nonunion, rather, it is the poor utilization of these substances in the metabolic processes that is chiefly responsible In scurvy and rickets, callus forms readily but does not become properly calcified until the vitamin deficiency has been corrected

DEFINITIONS

Delayed Union

The repair of a fracture takes time If a fracture does not heal within a certain period of time, delayed union is said to be present The time element for fracture healing varies greatly with the individual as well as with the bone involved Complete healing of a fracture, that is, the formation of lamellae across the fracture site, usually takes at least eight to ten months For practical purposes, however, a fracture is regarded as firmly healed when there is no motion or local tenderness at the fracture site and when the x ray reveals sufficient callus to obliterate the fracture site, and bone lamellae may be seen to pass over it In fractures of the lower end of the tibia, firm bony union often requires twelve to twenty weeks, whereas fractures of the upper third of the humerus often are united in three weeks In delayed union, osteogenesis is still progressing at the fracture site and attempts should be made to stimulate it It is often difficult to determine the exact time when delayed union ends and nonunion starts Progressively increasing motion at the fracture site is a good clinical indication of the failure of union

Nonunion

In nonunion, the reparative processes of the fracture have ceased The roentgenogram will reveal a sclerosis of the bone ends Nonunion may take the form of a true pseudo-arthrosis or a fibrous union of the fracture

EXTERNAL SKELETAL FIXATION AND ITS RELATION TO THE PROBLEM OF DELAYED UNION AND NONUNION

Böhler states that delayed union and nonunion are usually the result of treatment and not the injury itself. Nonunion is seldom seen in birds and animals in spite of the fact that malunion is common. This emphasizes the importance of *early active motion* as a factor in the satisfactory healing of fractures. It is the general belief that absolute fixation of bone, whether by external skeletal fixation or by internal fixation with plates and screws, is a predisposing cause of delayed union and nonunion. This is not true if early active motion is instituted, since the muscle action, adequate blood supply, free joint motion, and absence of demineralization will tend to help rather than retard bone union. On the other hand, if absolute skeletal fixation is undertaken by any method without early active motion, delayed union and nonunion will result in a higher percentage of cases.

When properly applied, external skeletal fixation provides a method for the prevention as well as the treatment of delayed union and nonunion. The fragments may be accurately reduced, rigidly fixed, and the adjacent joints may be actively moved throughout the entire period of healing. Muscle tone is sustained. Adequate circulation is provided. The integrity of the joints is not interfered with. The calcification of the callus progresses normally because of the good circulation. Distraction of the bone ends may be controlled by proper impaction of the fragments.

The treatment of delayed union and nonunion by external skeletal fixation has as its fundamental value the rigid fixation of the fragments while at the same time allowing freedom of motion of the adjacent joints. It can be applied to any of the bones as described in the section on special fractures, provided, of course, that the mineral content of the bone is adequate to permit the proper anchorage of the pins.

In the application of the splint for the treatment of delayed union and nonunion, all the necessary precautions for pin insertions should be carefully and meticulously carried out.

The operative procedure of choice will depend mainly

upon the extent of the nonunion and the condition of the bone ends In some cases the fracture site may simply be freshened and the bone ends firmly apposed (Fig 36) In others a full thickness bone graft may be used (Fig 93)

Cases of delayed union may require only fixation Controlled impaction of the fragments may be performed by activating the turnbuckle and if the fragments need correction they may be adjusted by means of the various adjusting screws Rigid fixation with activity is sufficient in most cases of delayed union but drilling of the bone ends may be performed if indicated to hasten reunion

SECTION IV

SPECIAL FRACTURES

CHAPTER IX

FRACTURES OF THE MANDIBLE

In recent years, both in England and in this country, considerable interest has been shown in the treatment of fractures of the mandible by external skeletal fixation. Waldron contributed in a large measures to the popularization of this method.

External skeletal fixation of the fractured mandible, which is usually considered practicable only in hospitals, may be necessary on board ship in order to avoid the complications resulting from interdental wiring when vomiting from seasickness or other causes intervenes.

Efficient cooperative teamwork between the surgeon and the orthodontist is necessary throughout the entire treatment because the ultimate aim is to obtain good occlusion. Malocclusion may result even in those cases in which anatomical reduction of the fracture has been obtained. Because of the fact that various degrees of malocclusion are so common, it is often difficult to ascertain the extent of displacement of a fractured mandible, and the corrective measures necessary to overcome it.

The treatment of fractures of the edentulous mandible is often a difficult problem. Control of the toothless fragment, whether by means of circumferential wiring around an intraoral splint or by wire traction through the angle of the mandible, is not always easy or adequate. While these fractures present difficult problems in reduction, any deviation from the normal in the ultimate result may be compen-

sated by dental prosthesis This is not the case in dentulous mandibles where not only accurate reduction is essential, but good occlusion is necessary Osteomyelitis occurs not only as a result of the injury in which the mucous membrane has been torn but also because of the necessity of extraction of the tooth in the line of fracture

Waldron states that "most fractures of the mandible are compounded into the oral cavity along the root surface of the tooth It is essential that reinfection of the deeper portions of the line of fracture through the periodontal space along the surface of the root be prevented, as far as possible, by as nearly complete immobilization of the fractured surfaces as may be secured" And again "prompt reduction and immobilization is the method to control and prevent infection of the fracture site"

In many cases, the fracture line runs through a remaining molar tooth, the extraction of which produces an edentulous fragment The resulting displacement of the edentulous fragment will vary according to the site as well as the direction of the fracture line If the obliquity of the fracture line runs downward and forward, the strong elevator muscles (masseter and internal pterygoid) attached to the proximal fragment can cause little serious displacement of the proximal fragment Unfortunately, however, this is not often the case Usually the fracture line runs obliquely upward and forward permitting typical upward, forward and outward displacement of the proximal fragment The distal fragment is displaced to the opposite side by the muscles attached to the normal side

TYPES OF FRACTURES OF THE MANDIBLE FROM THE STANDPOINT OF TREATMENT BY EXTERNAL SKELETAL FIXATION

1 Edentulous mandibles These may be classified into
   a Fractures of the mandible with short edentulous proximal fragment
   b Fractures of the mandible with long edentulous proximal fragment
   c Fractures of a completely edentulous mandible.

d Fractures of the mandible with edentulous proximal fragment and few remaining or worthwhile teeth in the distal fragment

e Multiple fractures of the mandible

2 Fractures of the dentulous mandible

3 Fractures of the mandible with loss of bone substance

Edentulous Mandibles

Fractures of the Mandible with Short Edentulous Proximal Fragment (Fig 24) —These are the most common type of fractures of the edentulous mandible The line of fracture is proximal to the first molar tooth, and usually runs through a remaining second or third molar In some cases, the line of fracture is at or slightly above the angle When the fracture extends through a remaining molar, the tooth itself is often loose Some surgeons regard extraction of the remaining molar as mandatory whenever the fracture extends through it, even when the tooth appears firm Such a procedure is controversial and opinion is divided Each case is a problem of its own and the procedure of choice will depend on associated problems involved

Whenever the fracture site is proximal to the first molar tooth, many surgeons prefer the conservative method of treatment, the teeth are simply wired and the proximal fragment is allowed to displace The disfigurement of the face in these cases is not serious and the functions of the jaw are not appreciably impaired These fractures, however, because they are compounded into the mouth in so many cases, require firm fixation to decrease the incidence of osteomyelitis as well as to give comfort to the patient Proximal edentulous fragments cannot be properly immobilized by mere wiring of the teeth distal to the fracture

Fractures of the Mandible with Long Edentulous Proximal Fragment—Fractures of the mandible in which the fracture line of the edentulous fragment is distal to the second molar require reduction and fixation of the proximal fragment Malunion, nonunion and serious dysfunction of the jaw often result in neglected or improperly treated cases

Fractures of a Completely Edentulous Mandible (Fig 27) —Fractures of a completely toothless mandible are often bilateral or multiple and are difficult to reduce and maintain in proper position Such cases are ideal for external skeletal fixation Immediately after the splint is applied and the fracture reduced the patient has use of his jaw with little or no discomfort Because this type of fracture occurs mainly in the aged the advantages of freedom of jaw motion are especially apparent and the patient is spared the unnecessary discomfort and complications of interdental splints and immobilization of the jaw

Fractures of the Mandible with Edentulous Proximal Fragment and Few Remaining or Worthless Teeth in the Distal Fragment —Such cases may be converted into completely edentulous cases by extracting the remaining teeth in the distal fragment thus greatly simplifying the problems of treatment of the fracture There will then be no problem of occlusion and the patient may have full use of his jaw during the entire period of immobilization when treated by external fixation

Multiple Fractures of the Mandible —External skeletal fixation is particularly desirable for the treatment of bilateral fractures of the mandible with edentulous proximal fragments There may be marked deformity due to the action of the genioglossus geniohyoid and mylohyoid muscles Where the distal fragment contains several worthless teeth it is better to extract them to convert the lower jaw into a completely edentulous one In those cases in which the distal fragment contains several good teeth proper occlusion of these teeth must be sought after If accurate occlusion cannot be maintained by means of external fixation alone the remaining teeth may be wired when the patient's condition permits A delay of one or two weeks is often very desirable because it allows a comfortable painless convalescence until the primary fracture reaction and swelling have disappeared

Fractures of the Dentulous Mandible

In difficult fractures of the dentulous mandible external skeletal fixation in conjunction with interdental wiring is

desirable In the treatment of fractured dentulous mandibles at sea, where vomiting from seasickness or some other condition is anticipated, *it should be the method of choice* In such cases, *if interdental fixation becomes necessary*, rubber bands should be used to fix the jaws together to assure satisfactory occlusion The rubber bands are easily removed by the patient in case of emergency In injuries of the oral cavity associated with injuries to the nasopharynx, external skeletal fixation becomes imperative as it permits treatment of these conditions and facilitates breathing in case of nasal obstruction

Fractures of the Mandible with Loss of Bone Substance

In extensive trauma with loss of bone substance and marked interruption of bone continuity, external skeletal fixation will maintain normal position, preserve contour, permit healing without muscle contracture, and facilitate bone grafting and reconstructive surgery.

THE ADVANTAGES OF EXTERNAL FIXATION IN THE TREATMENT OF FRACTURES OF THE MANDIBLE

1 *Control of the Displaced Fragment*—"External" control of the displaced edentulous fragment permits accurate *reduction, especially when combined with intraoral manipulation*

2 *Rigid Fixation*—Rigid fixation also decreases the incidence of osteomyelitis, as well as offers the choice basic treatment should osteomyelitis be present or complicate the fracture treatment

3 *Freedom of Motion of the Jaw*—The advantages of active jaw motion are numerous and varied.

a *In vomiting In cases where vomiting is present or* anticipated as a complication of a fractured jaw (seasickness gastric disorders, and so on) freedom of jaw motion is essential

b *In eating* The ability to eat regular food assures normal caloric and vitamin intake, and prevents the weight loss so often complicating fractures of the mandible The normal health and strength of the patient are thereby easily *maintained*

c *Psychological effect* The ability of the patient to open and close his mouth in combat zones is very soothing to his mental attitude, as it relieves his anxiety.

d *Care of mouth and teeth* External fixation permits proper oral hygiene and dental treatment, which is an essential part of the after-care of a fractured mandible Free access to the mouth and fracture site allows proper cleaning as well as adequate drainage should osteomyelitis or extensive caries complicate the fracture In those cases where the remaining molar tooth is in the line of fracture and where extraction is indicated, the tooth may be extracted with ease after the application of external fixation and the tooth socket may be treated daily for better healing and drainage

e *Simplifying after-care* The after-care in the treatment of edentulous fractured mandibles is greatly simplified because of the free motion of the jaw This obviates the dietary problem, results in freedom from pain and has a beneficial psychological effect on the patient It also decreases the problem of maintaining reduction by means of interdental splints, wiring of the teeth and wire traction through the mandible

4 *Special Advantages to Old People* —The above advantages are particularly desirable in older people

THE DISADVANTAGES OF EXTERNAL FIXATION IN THE TREATMENT OF FRACTURES OF THE MANDIBLE

1 The technique of the application of external fixation to edentulous fractures of the mandible is not easy except for those accustomed to the use of pin fixation Mastery of the problems results not only from experience in the various types of fractures, but also from the strict observance of the minutest details of its application

2 Exact occlusion of the teeth of the distal fragment may be difficult to maintain throughout the period of healing and therefore may require additional wiring of the teeth after the swelling and reaction have disappeared

THE APPLICATION OF EXTERNAL SKELETAL FIXATION TO FRACTURES OF THE MANDIBLE

Preparation of the Patient

The face is shaved and the skin prepared as for any surgical procedure on the mandible It is well to mark the site and line of fracture on the skin When in doubt, the fracture line should be explored through the skin with a hypodermic needle The assistance of a qualified dental surgeon is always desirable, not only to survey the problem on hand before the operation, but also to assist during and after the operation Proper x-ray films of the mandible must be on hand during the operation

Type of Anesthesia

The type of anesthesia will depend upon the condition of the patient and the facilities on hand Local and mandibular block are sufficient for the reduction of most mandib-

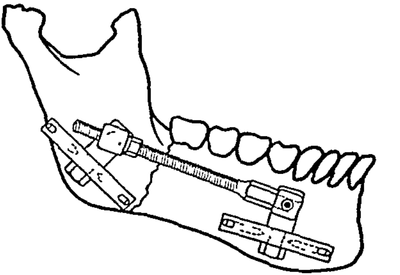


Fig 9.—Stader mandible splint as applied to a fracture anterior to the angle of the mandible

ular fractures In difficult cases, either intravenous or intratracheal anesthesia may be indicated (See chapter on Anesthesia)

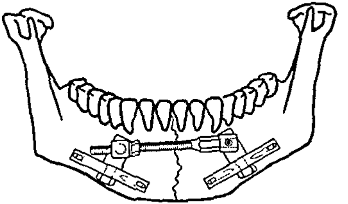


Fig 10—Stader splint as applied to a fracture of the symphysis region of the mandible

Pin Placements

A pin unit is applied to the proximal fragment first The position of the pins will vary according to the site of the fracture When the fracture line is at the angle of the mandible the upper pin unit must be applied to the ramus In every case it is necessary to avoid pin penetration into the fracture site If the pins are inserted about 1 cm from the edge of the mandible the inferior alveolar artery and nerve will not be injured (See cross section Fig 31 *A* *B*) The mandible pins have a stepped up point so that they will not penetrate the mandible too far (Figs 11 12)

The *first pin* is placed in the channel of the pin bar (Fig 12) and inserted through the skin to the mandible With the point of the pin the edge of the mandible is gently surveyed until a point about 1 cm from the edge is found and a firm steady purchase is then made on the pin directing the pin transversely into the mandible until it is felt to penetrate the bone (Fig 13) A firm steady purchase on the pin must be maintained throughout the entire drilling of the pin through the bone If unsteady or weak pressure is used the pin may easily slip and slide off the mandible If the direction of the pin is not transverse the pin may also slip off the edge of the mandible and thus penetrate the neck The operator must have complete control of the pin during its

insertion. (During the insertion of the pin the assistant exerts a constant steady counterpressure on the fragment with his finger in the patient's mouth. With his other hand, the assistant steadies the patient's head. In case of necessity, the operator may perform the entire procedure by himself, but he must then be careful to watch his sterile technique

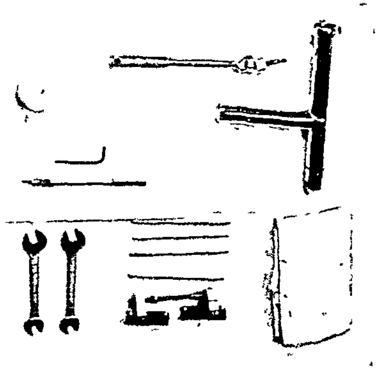


Fig. 11 —Layout of mandible splint and accessories. Splint, pins with shoulders, wrenches, small Allen wrench to secure pins in half-pin units, large Allen wrench to lock cable of flexible shaft drill in drill handle

and change gloves every time he inserts his finger in the patient's mouth until all the pins have been inserted.)

The *second pin* is passed through the channel of the pin bar in the same manner as the first and is inserted in its proper position at least 1 cm. from the edge of the mandible, care being taken not to penetrate the fracture site (Fig. 14). After the pins are locked in the pin bar by means of the

Fig 12—Pin placed in channel of pin bar

Fig 13—First pin drilled in mandible with flexible shaft hand operated drill

Fig 14 —Second pin drilled in mandible, pin bar held at least one fingerbreadth from the skin

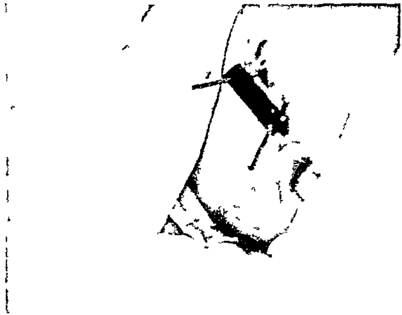


Fig 15 —Upper pin unit in place, pins locked in bars by means of the set screws

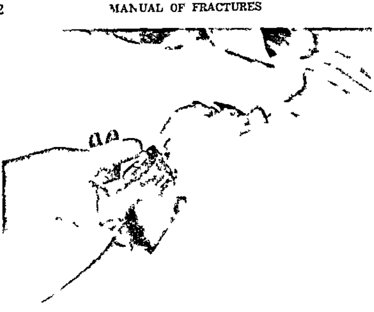


Fig 16 —Operator has control of proximal fragment by grasping pin unit

Fig 17.—Second pin unit applied Note transverse direction of pin and position of pin bar

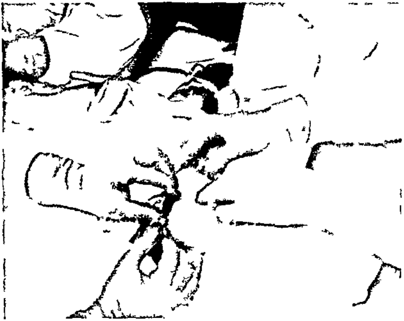


Fig 18.—Operator has control of both fragments by means of pin bars

Fig 19 —Connecting bar applied and fragments manipulated

small Allen wrench (Fig 11), the operator, by grasping the pin bar, has complete control of the proximal edentulous fragment (Figs 15 and 16) The *third pin* penetrates the distal fragment again about 1 cm from the edge of the man

Fig 20—Checking reduction, splint in place

Fig 21—Checking occlusion of teeth

dible, the pin bar being held parallel with the border of the mandible (Fig 17) A hypodermic needle may be employed to outline the fracture site It is essential at all times to stay as far away from the fracture site as possible When

Fig 22.—Cutting pins by means of pin cutter

Fig 23.—Operation completed Splint in place

the *fourth pin* has been inserted and the pins locked in the pin bar, the operator will have control of both fragments by grasping the pin bars (Fig. 18).

Application of the Connecting Bar and Reduction of the Fracture

The dental surgeon now proceeds to adjust the fragments intraorally and checks the occlusion of the teeth of the distal fragment as well as the position of the proximal

Fig. 24.—Lateral x-ray of fractured mandible with short proximal fragment, before reduction. Note single tooth in proximal fragment in line of fracture.

fragment. Forceful manipulation of the fragments by means of the pin bars is dangerous and unnecessary, and may cause loosening of the pins. It must be remembered that even though the pins may be securely inserted into the

Fig 25.—Anteroposterior and lateral x rays after reduction and application of the splint. Tooth has been extracted

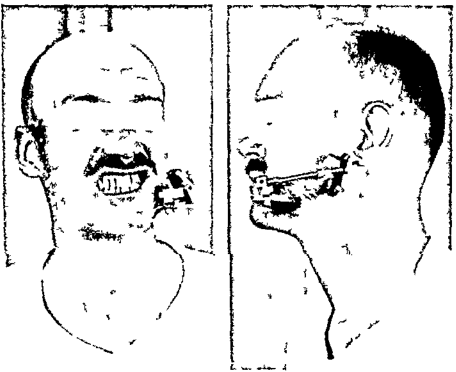


Fig 26.—Front and side views of splint on same patient as Figure 25

Fig. 27.

Fig. 28.

Fig. 29.

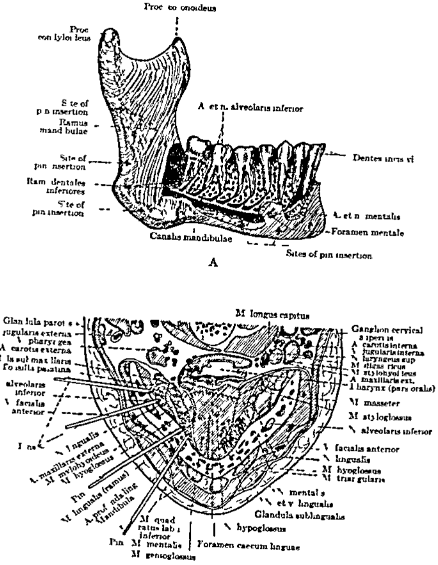
Figs. 27, 28, 29.—Multiple fractures of edentulous mandible with few remaining teeth. Upper jaw completely edentulous. No problem of occlusion. X-rays before reduction, after reduction and application of the splint, and final x-rays.

mandible, they may give way when undue force is exerted on them. *Intraoral manipulation of the fragments is easier, safer, and more accurate.*

When the major reduction of the fracture has been accomplished by means of intraoral adjustment by the dental surgeon, aided by external manipulation by the operator, the connecting bar is applied and the nuts tightened by hand. Accurate reduction is now obtained by intraoral and

FIG. 30.—Showing patient (Figs. 27, 28, 29) with splints in place. Note free mobility of the jaw and lack of pain. (Courtesy of Dr Doyle.)

external manipulation (Figs. 19 and 20). All set screws and nuts are now *firmly tightened with wrenches. Final* check of the reduction and occlusion is carried out before the patient is sent back to the ward (Fig. 21). It is best to obtain accurate reduction at once while the patient is still *under the anesthetic. The excess pin length is cut off by* means of the hydraulic pin cutter (Fig. 22). In multiple fractures, the pin units may be connected to each other (Fig. 31*a*).



A

B

Fig 31.—*A*, Mandible, showing sites of pin insertion *B*, Section through inferior portion of mandible upper surface, showing insertion of pins.

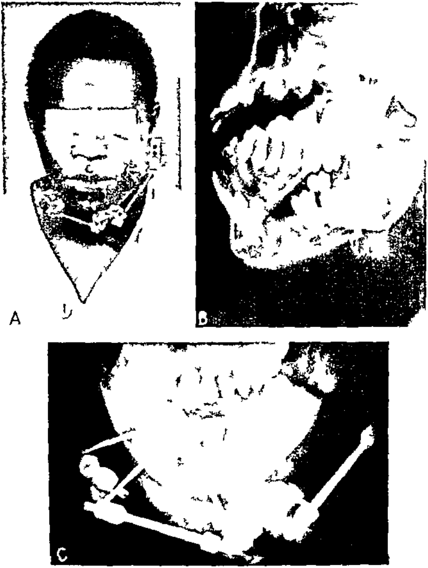


Fig 31a.—Splints connected to each other in fractures of the symphysis and angle of the mandible *A*, Multiple unit mandible splint applied *B* Preoperative x ray view *C*, Postoperative x ray view Dis traction of fragment was corrected by turnbuckle manipulation

Postoperative Care

If the operation was performed under general anesthesia the patient should be watched carefully until he has completely recovered from the anesthesia He may toss around in bed and traumatize the splinted jaw As soon as the patient has recovered from the anesthesia he usually has active use of his jaw without pain He is encouraged to use his mandible but not to use it excessively Necessary oral hygienic measures are carried out in the ward as well as in the dental clinic The pin sites are protected by small dry sterile dressings for the first twenty four or forty-eight hours and then left open The swelling usually recedes quickly but the occlusion must be checked from time to time (Fig 26) The normal lateral mobility of the mandible will often give the impression of malocclusion when the muscles of the opposite side tend to pull the mandible to that side The patient may however voluntarily bring the distal fragment in proper occlusion This apparent malocclusion must always be differentiated from actual malocclusion To prevent unnecessary strain on the splint and pins excessive motion of the mandible should not be allowed after the splint has been applied If indicated interdental wiring should be used as a temporary adjunct to treatment

ERRORS IN THE TREATMENT OF FRACTURES OF THE MANDIBLE BY MEANS OF EXTERNAL FIXATION

1 Neglect to make an accurate diagnosis as to the type of fracture the position of the fracture line and the type of displacement
2 Failure to select the proper anesthesia for adequate relaxation
3 Errors in pin placements—placing the pins too close to the fracture line
4 Failure to apply firm steady pressure while inserting the pins
5 Failure to maintain constant control of the pin by holding the handle of the flexible shaft drill against the chest

6 Failure to direct the pin transversely through the mandible to avoid slipping off the edge of the bone
7 Failure to stay about 1 cm from the edge of the mandible for the pin insertions
8 Failure to obtain accurate reduction by intra-oral manipulation
9 Failure to check occlusion of the distal fragment before connecting the splint
10 Allowing excessive use of the mandible after application of the splint The unnecessary strain on the splint and pins may produce loosening of the pins and displacement of the fragments

CHAPTER X

FRACTURES OF THE CLAVICLE

Fractures of the clavicle are comparatively common and nonunion is seldom seen In spite of the fact that anatomical reduction is not always obtained the functional results are usually satisfactory

In most cases conservative treatment is sufficient External fixation is only justifiable in certain selected cases especially in extreme injuries with marked loss of bone which would necessitate subsequent bone grafting

Application of the Splint to the Clavicle

Extreme care should be used in the insertion of the pins to avoid injury to the important underlying structures The pin units are applied as close to the ends of the clavicle as possible on its anterior surface The first pin is inserted into the medial fragment about 0 5 to 1 cm from the sternoclavicular articulation, the drilling being discontinued as soon as the pin is felt to engage the opposite cortex As the second pin is inserted, the pin bar should be held at a sufficient distance from the skin to allow for swelling The application of the second pin unit is slightly more difficult because of the convexity of the anterior surface The third pin is inserted about 0 5 to 1 cm from the acromioclavicular articulation in a slightly downward direction A hypodermic needle should be used as a pathfinder for the location of the proper pin sites After the fourth pin has been inserted, and the pins locked in the pin bars the operator has hand control of the fragments by grasping the pin bars Reduction of the fracture is obtained by gentle manipulation and the connecting bar is then applied

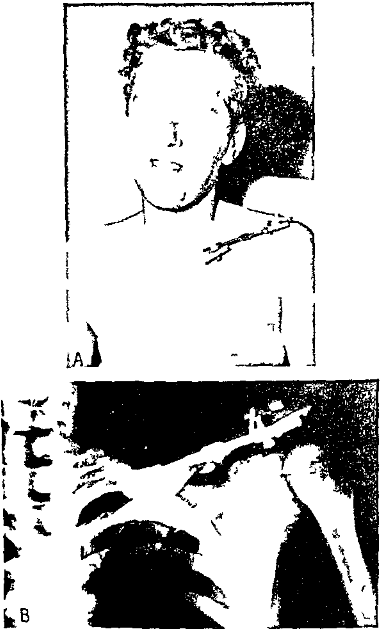


Fig. 32 (D. M.).—Comminuted fracture of left clavicle in a twenty one year-old male. *A*, Stader reduction splint applied. *B*, X ray film taken on first postoperative day. Free mobility of the entire extremity was obtained without discomfort.

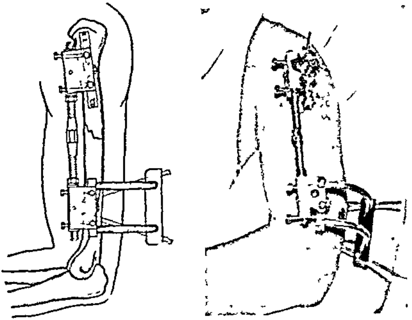
Postoperative Care

In view of the fact that the splint is applied only in extreme injuries a sling should be used to support the forearm and arm for a period of three weeks Gentle guarded motion of the extremity may be permitted daily The severity of the injury will be the determining factor in the amount and range of active motion permitted

CHAPTER XI

FRACTURES OF THE HUMERUS

Fractures of the humerus have been treated successfully by many methods, practically all of which, however, depend *upon some form of joint immobilization* either above or be-



A B

Fig 33.—A, Diagrammatic drawing of the modified Stader splint as applied to the humerus Note the projected pin bar, the upper pin unit *in* the lateral surface of the humerus, the lower pin unit *in* the posterior surface, and the parallel position of the extension bar with relation to the shaft of the humerus. *B*, Splint applied to humerus.

low the *fracture*, or both. *Joint immobilization in* these cases often produces prolonged disability. Any method of treatment which eliminates the necessity for immobilization of the joints would thus seem to offer a distinct ad-

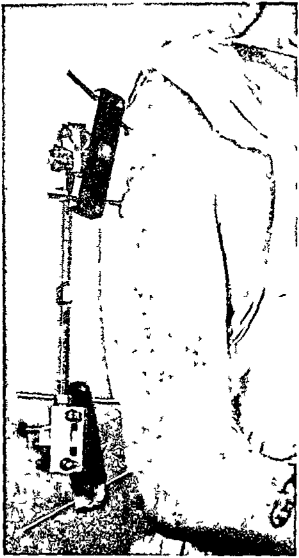


Fig 34—Lateral view of right arm showing application of regular humerus splint without projected pin bar

vantage The splint allows freedom of adjacent joints and permits more accurate reduction and firmer fixation The rigid fixation with this splint also decreases the tendency

toward excess callus formation, which not infrequently encroaches upon the radial nerve

The Stader splint (Fig 33) was modified to render it more adaptable to the treatment of fractures of the shaft of the humerus, by changes which made possible the application of the upper pin assembly to the lateral aspect of the arm, and the lower pin assembly to the posterior aspect of the arm This arrangement permits the connecting bar to be applied parallel to the shaft of the humerus, rather than obliquely, as would otherwise be necessary (Fig 34)

Reduction of fractures of the shaft of the humerus is usually easy, proper immobilization often troublesome, and functional restoration always problematical External fixation simplifies accurate reduction, insures constant rigid fixation, and permits immediate active use of the entire extremity with a minimum of discomfort

Indications for External Skeletal Fixation in Fractures of Humerus

External skeletal fixation by means of the Stader splint may be used to distinct advantage in

1 *Older patients, where the complications of joint fixation*, whether by plaster or by inactivity, are so commonly seen Those who have an underlying arthritic diathesis are especially prone to develop pain and limitation of motion of the joints even after limited fixation These patients require active use of the shoulder, wrist and hand as well as the elbow, in order to prevent the handicaps that result from prolonged fixation of joints
2 Difficult fractures of the shaft, where adequate reduction, fixation and functional restoration cannot be *obtained by the usual methods In this class are* primarily the badly comminuted fractures
3 Compound fractures of the shaft, especially the gunshot fractures, where external rigid fixation during the operation of wound excision or débridement and *shell fragment extraction* is distinctly advantageous

4 Fractures of the shaft of the humerus in the proximity of the radial nerve Injury of the radial nerve may occur at the time of the accident, or from injudicious manipulation of the fragments during reduction, from insufficient fixation causing secondary displacement of the fragments, or from excessive callus formation Excess callus formation is due mainly to improper or nonrigid immobilization of the fragments

5 Fractures of the shaft of the humerus with loss of bone In this case the splint allows for accurate rigid distraction of the main fragments until the time is at hand when a bone graft can be safely inserted

Generally speaking, all fractures of the shaft of the humerus in which the proximal and distal fragments are of sufficient length to engage properly the converging pins of the half-pin units are amenable to treatment with the regular humeral splint This would include those fractures whose fracture lines extend at least 3 inches from the shoulder and elbow joints, and exclude fractures of the surgical neck as well as short supracondylar fractures

FRACTURES OF THE SHAFT OF THE HUMERUS

Application of the Splint

Anesthesia—Application of the splint as well as reduction of the fracture may be performed under local anesthesia (See chapter on Anesthesia)

Preparation of the Patient—A complete surgical preparation of the skin of the extremity is performed

Preparation of the Splint—Before sterilization in the autoclave or by boiling, the entire splint is assembled to make certain that all essential parts are on hand and in good order, including the projected pin bar

Pin Placements—In order to avoid penetration of important structures the upper pin unit is placed on the lateral aspect of the arm The *first pin* is inserted about one fingerbreadth from the top of the acromion about 1 cm

lateral to the bicipital groove It is inserted directly through the skin and deltoid muscle and must penetrate both cortices Because of the cancellous character of the bone in this area *great care must be exercised* in the insertion of the pin so as to avoid overpenetration Undue protrusion of the pin may injure important structures (see Fig 35) During the insertion of the first pin the *pin bar must be held parallel to the proximal fragment* In the case of fractures above the insertion of the deltoid the upper fragment *is displaced medially by the strong pectoralis major muscle* therefore the pin bar should be held slightly medially in relation to the skin of the arm during the insertion of the first pin In fractures below the insertion of the deltoid the latter muscle counteracts the pull of the pectoralis so that there is little displacement of the upper fragment except for overriding

The *second pin* is *inserted directly through the skin and* deltoid muscle to the bone By gently feeling the cortex of the bone with the point of the pin the apex of the convexity of the fragment is ascertained and the pin inserted through both cortices During the drilling of the second pin the pin bar is held at least ¼ inch from the skin to allow for reactionary edema and the operator or an assistant exerts *firm counterpressure on the medial surface of the upper fragment* When both upper pins have been inserted they are locked in the pin bar by means of the set screws and the operator then has firm control of the upper fragment by grasping the pin bar

The special *projected pin bar* is used for the lower pin *unit because the pins are best inserted into the posterior* surface *of the lower fragment and the projected pin* bar allows the turnbuckle bar to be placed on the lateral surface of the arm *parallel to the humerus* so as to provide maximum adjustments by the splint as well as impaction and distraction in the longitudinal axis of the humerus (see Fig 33 *A* and *B*) The posterior surface is selected for obvious anatomical reasons

The *third pin* (first pin of the lower pin unit) is therefore placed in the channel of the projected pin bar and in

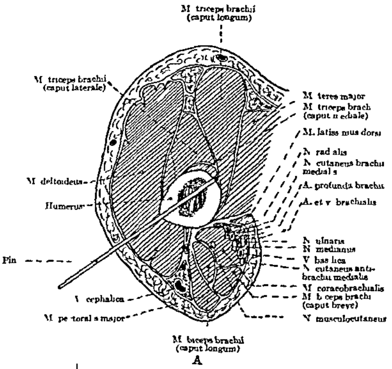

M triceps brachi (caput longum)
M triceps brachi (caput laterale)
M teres major
M triceps brach (caput n edale)
M. latiss mus dorsi
N rad alis
N cutaneus brachii medial s
A. profunda brachii
A. et v brachialis
M deltoideus
Humerus
N ulnaris
N medianus
V bas lica
N cutaneus antibrachii medialis
Pin
M coracobrachialis
M b ceps brachi (caput breve)
V cephalica
M pe toral s major
N musculocutaneus
M biceps brachii (caput longum)
A
Pin
M tr ceps b achii
Humerus
Septum intermusculare humeri laterale
M triceps brach i
N cutaneus antibrachii dorsalis
Septum intermusculare humeri mediale
M extensor carpi radialis longus
M brach oradialis
N radialis
M brachialis
N ulnaris
V cephal ca
V basil ca
N medianus
N cutaneus antibrachii lateralis
N cutaneus antibrachii medialis (ramus volaris)
M bicep brach i
V brachialis
A. brachialis
B

Fig 35

serted into the posterior surface of the lower fragment about two fingerbreadths from the tip of the olecranon It passes through the triceps muscle and fascia and penetrates the very dense bone above the olecranon fossa Constant control of the pin insertion must be exercised so as to avoid excessive overpenetration During the insertion of the third pin the projected pin bar must also be held parallel to the distal fragment. Counterpressure on the anterior aspect of the distal fragment is made either by the operator or by an assistant

The *fourth pin* is inserted with the projected pin bar parallel to the long axis of the distal fragment and again at least ¼ inch from the skin When the third and fourth pins have been locked in the projected pin bar, the operator, by grasping the projected pin bar, has firm hand control of the distal fragment

Application of a regular pin unit to the lateral aspect of the distal fragment is difficult and dangerous because the humerus in this region comes to a narrow border and there is danger of sliding off

Application of the Connecting Bar Assembly and Reduction of the Fracture

With complete control of each fragment through the medium of the pin bars the operator may easily reduce the fracture by hand In transverse and short oblique fractures, crepitation is gently elicited so as to make certain that no soft parts are interposed between the fragments If such is the case the interposed tissues usually become disengaged by simply rotating the fragments on each other In order to make certain that the rotational displacement is corrected and the humerus is in proper alignment, a guide line may be drawn from the greater tuberosity to the lateral condyle (Abduct the humerus 90 degrees and rotate outward 90 degrees using gentle traction) As the operator

---

Fig 35.—A Section through right upper arm immediately below axilla. Upper surface showing recommended position of Stader pin *B* Section through the right upper arm 1 inch above the epicondyles Upper surface showing recommended position of Stader pin.

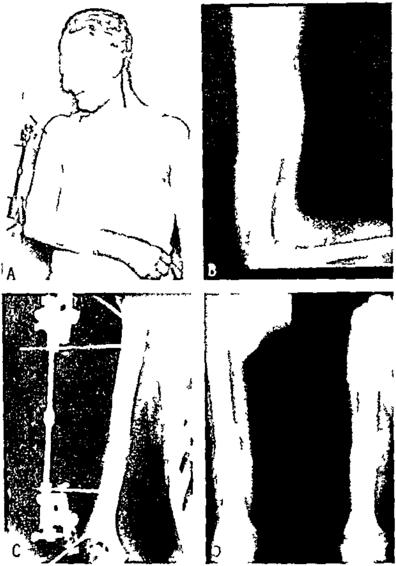


Fig 36.—Case of D O a fifty two year-old male who was seen with malunion of the midshaft of the humerus of six months' duration Six months of plaster immobilization had caused stiffness of all the joints from the tips of the fingers to the shoulder The splint was applied and the eburnated ends of the fragments were freshened and the fracture reduced and firmly impacted under direct vision Firm

holds this position with the pin bars an assistant attaches the connecting bar assembly and tightens all adjusting screws and lock nuts by hand Exact reduction may now be performed (under fluoroscopic guidance or by study of x ray plates) by means of the various adjusting screws controlling each fragment and by activating the turnbuckle bar *for traction and impaction If circumstances require* delayed reduction, the splint is made secure by tightening all lock nuts and the adjusting screws on each other by means of the wrenches The practice of passively flexing and extending the elbow joint, while the patient is still under the anesthetic, to gain more motion of the elbow has been discontinued It was found that this increase in elbow motion was only temporary

Postoperative Care and Length of Immobilization

Immediately after the application of the splint, whether the fracture was treated by delayed or immediate reduction, there is usually free active use of the entire extremity with minimal discomfort The treatment is *ambulatory as soon as the patient is over the effects of the anesthetic* In severe fractures with marked swelling, the arm is kept elevated for the first twenty-four to seventy two hours, or longer if necessary Active exercises of the entire upper extremity are instituted as soon as the condition permits Flexion and extension of the elbow are always limited because the lower pins pass through the triceps Elevation of the arm is also limited because the upper pins pass through the deltoid muscle The remaining use of the extremity is usually sufficient, however, to provide an uneventful convalescence and early return of full function within a short period after the removal of the pins Most patients are encouraged and show a desire to employ their injured arms in active movements, including the lifting of weights and working about the ward Many can be discharged from

bony union resulted and the splint was removed at the end of three months No bone graft was used.

A The humeral splint applied *P* Preoperative x ray film *C* Immediately postoperative *D* Three months later

the hospital to go about their usual activities within a few days The pin sites are protected by small dry, sterile dressings for a few days and then should be left absolutely undisturbed *The function of the radial nerve is always tested before and after treatment*

A B C

Fig 37.—Comminuted fracture of midshaft of humerus *A* Before reduction. *B* After reduction *C* Final x rays

The splint is not removed until firm bony union has occurred This will depend upon the type of fracture as well as the age and general condition of the patient Usually fractures of the shaft of the humerus are firm within four to eight weeks Oblique and spiral fractures are often firm within four weeks whereas transverse fractures require

eight weeks or more It is better, as a rule, to err in longer immobilization than to take the splint off too soon because the ordinary complications of prolonged fixation do not have to be considered

Routine Impaction in Transverse Fractures

In order to avoid the dangers of delayed union and non union in transverse fractures of the shaft of the humerus

Fig 38—Fracture of humerus before and after impaction with the turnbuckle

the fragments are routinely impacted (firmly apposed) on the tenth day of treatment (see Fig 38) During the im paction by means of the turnbuckle of the splint, the fore-arm and the distal fragment are held in proper alignment by an assistant The lock nuts of the turnbuckle must first

be loosened and after the impaction again tightened securely Impaction of a fracture of the humerus need not be strong Excessive impaction produces bone injury delays union and produces excess callus which is undesirable in the region of the radial nerve Check x rays are taken es

A B C

Fig 39 —Fractured humerus with marked interposition of soft parts *A* Before reduction *B* After reduction *C* Final x rays Clinical union Note good periosteal callus and poor endosteal regeneration

pecially after each impaction and during the period of immobilization to determine the position of the fragments as well as the callus formation and union of the fracture

57 •

SUPRACONDYLAR FRACTURES OF THE HUMERUS

Supracondylar fractures in adults may be treated satisfactorily by external skeletal fixation. In such cases, a half-pin unit is applied to the lateral surface of the upper third of the humerus, and a second half-pin unit to the lateral surface of the upper third of the ulna (Fig. 40). The adjusting mechanism of the lower end of the splint is removed so that the end of the connecting bar may be passed directly

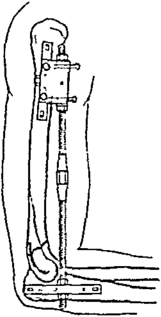


Fig. 40.—Diagrammatic drawing of special application of the humerus splint for supracondylar fractures of the humerus. Note position of the lower pin unit in the lateral surface of the upper third of the ulna, and the connecting bar inserted directly through the hole in the pin bar and secured by a nut above and below the bar. The elbow is flexed at right angles.

through the aperture in the pin bar and secured to it by nuts, one above and one below the pin bar. When the connecting bar is secured to both pin units the elbow joint is transfixed at a right angle. Necessary distraction is obtained by activating the turnbuckle and reduction is performed by gentle manual manipulation. A posterior plaster-of-paris splint is advisable for protection and support.

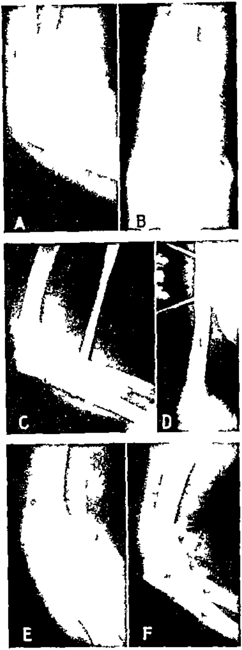


Fig 40a.—Three-weeks-old supracondylar and intercondylar fracture of the humerus with marked displacement. *A B* Before reduction *C D* After reduction and application of the splint (see Fig 40a) *E F* Final x rays

CHAPTER XII

FRACTURE OF RADIUS AND ULNA

The incidence of fractures of the forearm in the U S Navy and Marine Corps is exceeded only by fractures of the leg Fractures of the bones of the forearm should be treated conservatively when displacement is absent and when proper position is easily retained Unfortunately, this cannot be accomplished in many types of these fractures In such cases, external skeletal fixation is a very useful method of treatment because it permits accurate reduction and retention of the fragments without immobilization of the elbow or wrist

Fractures of the forearm for purposes of treatment by external skeletal fixation may be divided into

1 Fractures of the shaft of the radius
2 Fractures of the shaft of the ulna
3 Fractures of the shafts of both bones of the forearm
4 Comminuted fractures and fracture dislocation of the lower end of the radius and ulna

FRACTURES OF THE SHAFT OF THE RADIUS

Fractures of the shaft of the radius may be conveniently divided into those of the upper, middle and lower third Those in the upper third are above the insertion of the pronator teres The biceps and short supinator are the only muscles attached to the upper fragment, displacing it in a position of flexion and supination The lower fragment together with the hand will always be in a position of extreme pronation *In fractures of the middle third of the radius,* below the insertion of the pronator teres, the upper fragment lies in midposition because the pronator teres neutralizes the pull of the supinators (biceps and supinator brevis) The lower fragment with the hand will again lie in pronation because the pronators are stronger than the

supinators In fractures of the lower third the proximal fragment remains in midposition while the distal fragment is displaced toward the ulna and forward This displacement of the distal fragment is due not only to the pull of the pronator quadratus but mainly to the action of the extensors of the thumb (abductor pollicis longus and extensor pollicis brevis) which wind around the back of the lower end of the radius from their ulnar origin and push the lower fragment forward and toward the interosseous space when the forearm is pronated The radius is also shortened causing the typical dislocation of the distal radio ulnar joint and producing the usual prominence of the lower end of the ulna

Accurate reduction of fractures of the shaft of the radius is usually easily obtained by proper traction on the thumb supination of the forearm and digital manipulation of the distal fragment The abductor pollicis longus and extensor pollicis brevis supinate the forearm as well as extend the thumb therefore these muscles become relaxed by strong traction on the thumb and supination of the forearm and at the same time become disengaged from the fracture site Reduction of fractures of the shaft of the radius are often extremely difficult if manipulation is attempted without first applying adequate traction on the thumb with the forearm in supination The amount and length of traction will depend upon the musculature and strength of the fore arm because the amount of shortening is usually proportional to it

Whereas it is usually easy to reduce fractures of the shaft of the radius maintaining accurate reduction until firm bony union has occurred is often difficult The fragments are especially liable to become displaced in the fractures of the upper and lower thirds Inadequate inconstant fixation leads to delayed union and to nonunion as well as to secondary displacement of the fragments Motion at the fracture site with plaster fixation is mostly rotary which especially predisposes to delayed union and nonunion In order to sustain the integrity of the distal radio ulnar joint with its torn capsule many fractures of the shaft of the radius

require transfixation with wires or pins to prevent secondary luxation or displacement In order to avoid these difficulties many surgeons routinely "plate" fractures of the shaft of the radius

Functional restoration to be ideal should begin immediately after immobilization and include pronation and supination of the forearm as well as active motion of the joints not requiring fixation

The Advantages of and Indications for External Skeletal Fixation in the Treatment of Fractures of the Shaft of the Radius

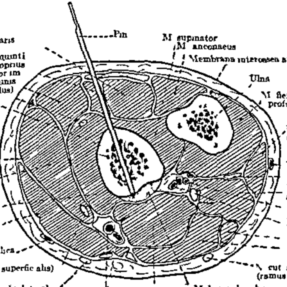
External fixation by means of the splint permits accurate anatomic replacement of the displaced fragments, constant rigid fixation, and active motion and use of the entire extremity including pronation and supination of the forearm from the first postoperative day It is indicated whenever the above advantages are desired and whenever reduction fixation and restoration of the function can not be adequately obtained by manipulation and plaster immobilization External fixation is contraindicated in those cases in which the skin areas for pin insertions are infected or devitalized

Application of the Splint to the Radius

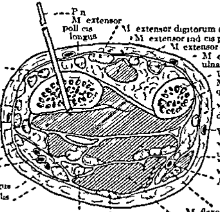
Anesthesia —Local or brachial plexus anesthesia may be used in applying the splint to the radius

Preparation of the Patient —The skin and the patient are prepared as for any surgical operation on the forearm The x ray films are placed in view so that the operator may readily acquaint himself with the site of fracture the planes of the fracture line, as well as the displacement of the fragments

Pin Placements —The posterior interosseous nerve (muscular branch of the radial) winds around the upper end of the radius about 1 inch from the head The operator, therefore, must be careful in applying the upper pin unit. The first pin is inserted about two fingerbreadths from the head of the radius on its lateral surface (Cross section Fig 41)



A



B

Fig 41.—*A*, Section through right forearm, 2 inches below elbow Upper surface, showing insertion of pin. *B*, Section 1 inch above styloid process of right radius Upper surface, showing insertion of pin

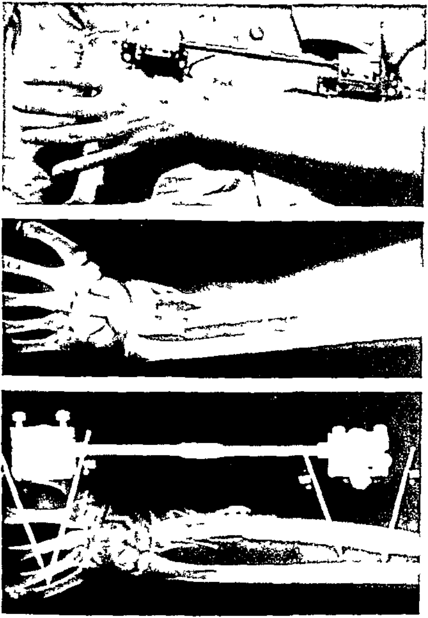


Fig 42 —Photograph and x rays to demonstrate the use of the regular radius splint in the treatment of comminuted fractures and fracture-dislocations of the lower end of the radius Note lower pins through metacarpals Pins were slightly retracted after this x ray was taken Old gunshot fracture X rays before and after operation

The pin should be inserted directly through the skin to the bone and the apex of the convexity determined by gently probing the cortex of the bone with the point of the pin As soon as this point is determined a steady and constant purchase on the bone is held until the pin has penetrated both cortices During the insertion of the first pin the pin bar must be held parallel to the proximal fragment The radial nerve will not be injured if the pin is carefully placed and inserted Unnecessary jabbing around and through the tissues with the pin should be scrupulously avoided

The second pin is now inserted under the same precautions as those observed in the insertion of the first pin and while the pin bar is held at least ¼ inch from the skin In order to make certain that this pin does not enter the fracture site a long hypodermic needle may be used to probe the fracture before the introduction of the pin When both pins have been locked in the pin bar the operator has firm control of the upper fragment by means of the pin bar Before applying the lower pin unit the distal fragment should be placed in line with the proximal in a position of supination

The third pin is inserted into the lateral or posterolateral surface of the lower end of the radius about one or two fingerbreadths from the tip of the styloid process It is necessary to avoid piercing the abductor and extensor tendons of the thumb (Cross section Fig 41) As usual during the insertion of this pin the pin bar should be held parallel to the long axis of the distal fragment When the fourth pin has been inserted (the pin bar again being held ½ inch from the skin) and both pins locked in the pin bar the operator will have complete control of both fragments through the corresponding pin bars Skin tension is avoided during the insertion of all pins

Reduction of the Fracture and Application of the Connecting Bar Assembly

Depending upon the type of fracture and character of the displacement the fracture is gently and carefully manipulated by means of the pin bars while an assistant maintains traction on the thumb The distal fragment must be

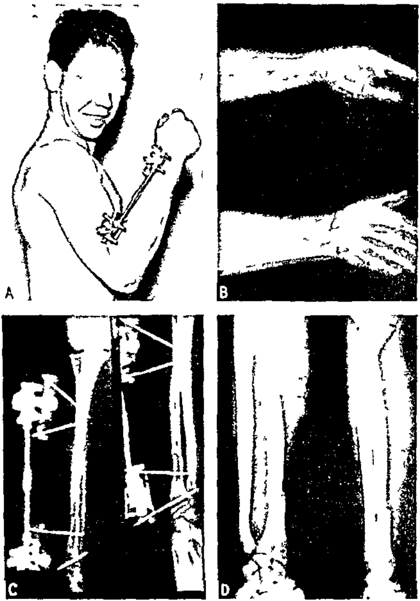


Fig 43.—Transverse fracture of radial shaft at junction of middle and lower thirds, with anterior displacement of distal fragment, and radio-ulnar joint displacement. *A*, Splint applied *B*, Preoperative x ray film *C*, Postoperative x ray view *D*, X ray showing final result, nine weeks after injury Firm bony union. No protective cast

derotated into supination during the reduction End to end approximation of the fragments may be felt by manipulating the pin bars When manual reduction has been completed an assistant attaches the connecting bar assembly and tightens all adjusting screws and lock nuts by hand Complete exact reduction may now be obtained if desired under fluoroscopic control or by proper anteroposterior and lateral x rays Distraction is accomplished by activating the turnbuckle by hand or with a wrench Complete reduction of the fragments is obtained by means of the various adjusting screws which control each fragment During the distraction and adjustment of the fragments it is best to have an assistant hold the hand together with the distal fragment in proper alignment This can be dispensed with if the rotation is locked by means of the lock nuts of the turnbuckle before the individual fragments are manipulated by means of the adjusting screws When the reduction is complete the fragments are mildly impacted in the case of transverse fractures before the splint is made secure All adjusting screws are then snugly tightened against each other and all lock nuts firmly tightened to insure complete splint stability

FRACTURES OF THE SHAFT OF THE ULNA

In fractures of the upper third of the shaft of the ulna with anterior dislocation of the head of the radius the splint offers a simple and ideal method of reduction and fixation of the fracture dislocation As this fracture is usually caused by direct trauma to the ulnar surface of the forearm it is often compounded The proximal fragment is displaced anteriorly by the direction of the trauma as well as by the brachialis anticus muscle and the head of the radius is forced forward tearing through the annular ligament and coming in contact with the humerus Damage to the radial nerve at the time of the injury or resulting from delayed reduction is not uncommon and is due to pressure on the nerve by the head of the radius

Application of the Splint to the Ulna

The ulna, being almost subcutaneous throughout its entire length, presents few hazards or difficulties in the pin insertions or placements. The pins may be inserted medially, laterally, or posteriorly in the upper fragment, and laterally or posteriorly in the lower fragment. The first pin should be inserted at least two fingerbreadths from the tip of the olecranon to avoid entering the elbow joint as well as injuring the ulnar nerve. The same general rules governing the pin insertions hold true as for the radius. The pin bars are held parallel to the long axis of the fragment as well as at least ½ inch from the skin. In the case of fractures of the upper third of the shaft of the ulna with anterior dislocation of the head of the radius, the upper pin bar should be held in slight flexion (direction of displacement of the upper fragment). By grasping the upper pin unit, the proximal fragment is manipulated into position while, at the same time, the head of the radius is pressed back into its normal position. As soon as the connecting bar assembly has been connected and the splint made rigid, the fracture dislocation is reduced and fixed and the head of the radius will usually remain in its normal position.

The first pin of the lower pin unit is inserted at least two fingerbreadths from the tip of the ulnar styloid. The pin unit is applied in a similar manner as on the radius.

FRACTURES OF THE SHAFTS OF BOTH BONES OF THE FOREARM

The actions of the muscles of the forearm are complicated. Besides pronation and supination which are the most important functions and without which the usefulness of the extremity is seriously impaired, the muscles must also flex and extend the wrist and fingers. In fractures of both bones of the forearm the complicated displacements of the fragments will depend mostly upon the site of the fracture. The same rules that govern the displacement of fragments in the case of the radius alone also hold here except that the

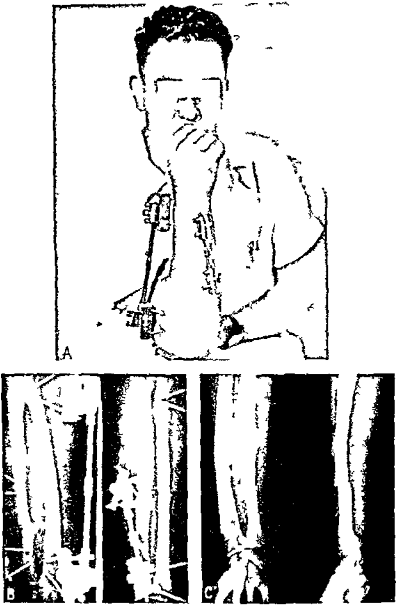


Fig 44.—Fracture of the radius and ulna in the midshaft *A* Splints applied *B* Postoperative x ray film *C* Ten weeks after injury Firm bony union Note smaller splint on ulna

displacements are more pronounced The degree of shortening will depend upon the type and extent of fracture as well as the strength of the muscles As a general rule, the stronger the muscles the greater the shortening The muscles are especially strong on the radial side of the fore arm causing a greater shortening of the radius and a tendency to pull the radius toward the ulna The radial styloid will be displaced upward in relation to the ulnar styloid *The hand and distal fragment are usually in pronation because* the pronator flexor group of muscles are stronger than the supinator-extensors In fractures above the insertion of the pronator radii teres, the upper fragment usually is displaced in supination and flexion due to the action of the supinator brevis and biceps The biceps is a strong supinator of the forearm Delayed union, malunion and nonunion are not infrequently found, especially in the radius

External fixation when properly applied will tend to avoid these sequelae While no perfect method has been established, external skeletal fixation has a distinct and obvious advantage over transfixations by pins or wires incorporated in plaster

Application of the Splint to Fractures of Both Bones of the Forearm

As a general rule, a splint should be applied to each bone *In cases, however, where wounds of the ulnar side of the* forearm contraindicate the use of the splint on the ulna satisfactory immobilization of the forearm may be obtained by means of a splint on the radius alone The splint on the ulna alone is very unsatisfactory and requires the *application of a plaster cast to obtain immobilization of* the radius

A splint is applied to the radius first, as described under the treatment of fractures of the shaft of the radius When the radius fracture has been reduced and fixed, the case now *becomes a fracture of the ulna alone A second splint is* then applied to the ulna The major reduction is performed by hand through the pin bars, before connecting the external adjusting bar assembly Secondary adjustments by

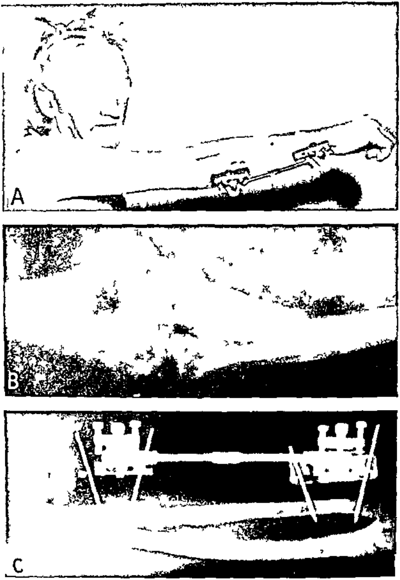


Fig 45.—Malunited fracture of upper third of right ulna and anterior dislocation of head of radius *A* Regular radius splint applied *B* Preoperative x ray film *C*, Postoperative x ray view Firm union in twelve weeks.

means of the adjusting screws may be performed under the fluoroscope or guided by anteroposterior and lateral x-rays. If the lower fragments are properly lined up in supination and traction during the reduction and held in proper position by means of the connecting bar, if the ends of the fragments are felt apposed by gently elicited crepitus, if all visible and palpable deformities are manually corrected, the chances are that the fracture has been properly reduced. All anatomical landmarks will appear in proper position. Full passive flexion, extension, pronation and supination are usually possible immediately after the splints are made secure while the patient is still under the anesthetic. Accurate anatomical reduction may now be completed unless it is contraindicated by excessive swelling or other reasons. The integrity of the nerve and blood supply should be ascertained after the operation.

Period of Immobilization in the Splint

The splint usually remains until firm bony union has occurred. Clinical union may be tested by removing the connecting bar and gently manipulating the fragments; if not firm, the connecting bar is immediately replaced. If desirable, the splint may in certain cases be removed as soon as the fragments have sufficiently united and a plaster cast applied.

Functional Activity in the Splint

In the majority of cases of fracture of the radius and ulna treated by the splint, active motion of the entire extremity is permitted as soon as the general condition of the patient and the local condition of the part permit. Full active pronation and supination are usually not obtained until the pins are removed, but varying degrees are always possible. Active flexion and extension of the wrist and fingers is usually well within normal limits but the strength of the hand grip may be decreased. Most patients are able to eat and shave and carry on with light duties.

BADLY COMMINUTED FRACTURES AND FRACTURE-DISLOCATION OF THE LOWER ENDS OF THE RADIUS AND ULNA

The treatment of badly comminuted fractures of the lower ends of the radius and ulna with or without dislocation

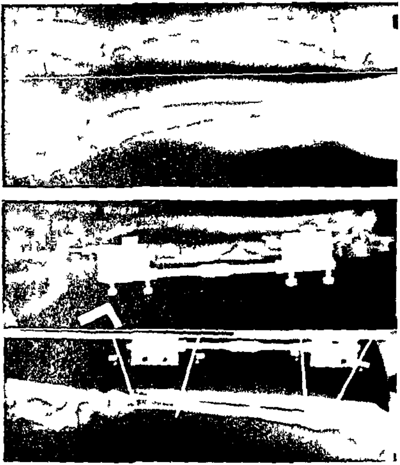


Fig 46—Fracture of midshaft of radius with (butterfly) third fragment, before and after reduction

of the wrist is often difficult and unsatisfactory The proper reduction of this type of fracture or fracture dislocation is usually easily attained by adequate traction but the prob

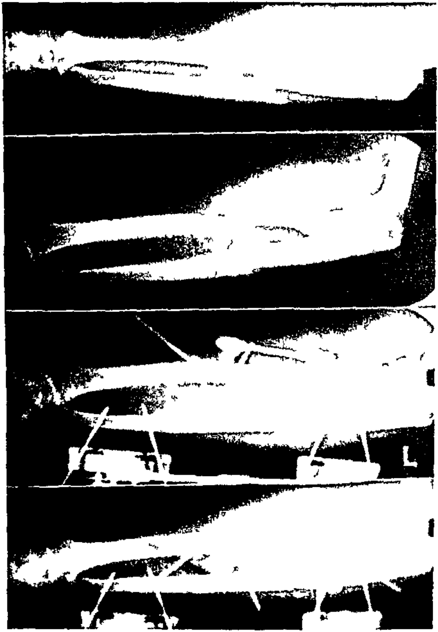


Fig 47.—Fracture of both bones of the forearm at the junction of the upper and middle third before and after reduction. Firm bony union in eleven weeks with normal function of the forearm

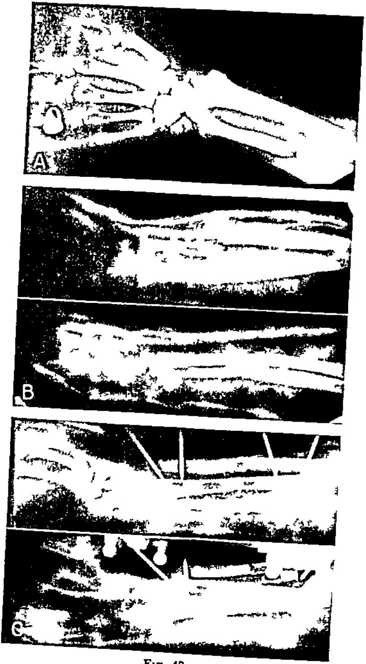


Fig 48

lem is to hold this reduction. When this type of fracture is compounded or associated with extensive soft tissue damage, such as in the case of associated burns, the problem is even more complicated. The regular radius splint is adequate for the treatment in these cases by transfixing the wrist from the metacarpals to the shaft of the radius.

Pin Placements and Application of the Splint

The first pin unit is applied to the lateral surface of the hand, the pins penetrating the second and third metacarpal bones. Traction by means of the second and third metacarpal bones is anatomically justified because these bones complete a single line of force through the radius by means of the adjacent carpal bones and ligaments which articulate with the wrist. The first pin is inserted into the lateral surface of the second metacarpal just below the head. Its passage through the second and third metacarpal bones is easily felt. The second pin penetrates the lateral surface of the base of the second metacarpal and its passage through the second and third metacarpal bones is also easily felt. The pin bar is held at a reasonable distance from the skin during the insertion of the second pin. The upper pin unit is applied to the lateral surface of the radius, about its middle third. After the application of the pin units, the operator has complete control of the hand and forearm by grasping the pin bars in his hands (Fig. 42).

Straight traction on the fingers should be applied for at least ten minutes with the elbow flexed at right angles, and the forearm in midposition. The traction should be slow and steady and not jerky. After proper hand traction most of the deformity will be spontaneously reduced. The connecting bar assembly is then applied and hand traction is discontinued. By activating the turnbuckle the wrist may be distracted and sufficient space developed between the

---

Fig. 48.—Illustrating combined conservative treatment and application of splint in multiple fractures of the forearm with dislocation of the wrist. *A*, X-ray view before reduction. *B*, After conservative treatment and plaster cast. *C*, Anatomical reduction of ulnar fracture after application of small Stader splint.

capitate and radius for replacement of the displaced semi lunar bone Any remaining displacement of the fragments is corrected by manual manipulation and if necessary aided by the adjusting mechanism of the splint A protective plaster cast is seldom necessary Fixation of these fractures and fracture dislocation of the wrist by this method permits active use of the fingers and elbow

CHAPTER XIII

FRACTURES OF THE FEMUR AND PELVIS

FRACTURES OF THE FEMORAL SHAFT

The most serious of all fractures of the shafts of long bones are those of the femur The gravity of these fractures is due, in most instances, to the severe shock that accompanies them Transportation of the patient without immobilization of the fracture may cause death from shock At sea, immobilization by means of a plaster-of paris cast affords serious handicaps because, if it becomes necessary for the injured man to abandon ship the cast will act as an anchor Therefore, in the transportation of persons with this type of injury over long distances and under such conditions external skeletal fixation becomes indicated Treatment of fractures at sea by traction suspension methods is obviously difficult and often impossible

The easiest type of fracture to treat is that occurring in the middle third of the shaft and probably the most difficult is that in the lower third The great majority of fractures of the shaft of the femur from the subtrochanteric to the supracondylar region may be treated by external skeletal fixation with the splint. The proximal and distal fragments need only be long enough to properly engage the converging pins of the half pin units The pins properly engage the femoral fragment when they emerge from the opposite cortex at least a centimeter apart The method is applicable to fractures of the shaft from 1 inch below the lesser trochanter to 2 inches above the condyles

Application of the Splint to the Femur

A local anesthetic (0 5 per cent procaine) should be used whenever possible In the absence of severe shock and when not contraindicated a small dose of a spinal anesthetic (75 to 100 mg of procaine) gives satisfactory anesthesia and

muscle relaxation for reduction The entire thigh is prepared as in the case of open reduction

Pin Placements

In every femoral shaft fracture it is important to place the pins as close to the extremities of the bone as the ana-

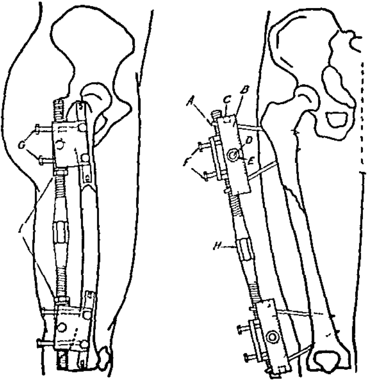


Fig 49 —Schematic drawings of femoral splint. *A* Stainless steel pins *B*, Pin blocks *C*, Set screw locking pins *D*, Hinge bolt. *E*, Nut attaching pin block to hinge bolt *F*, Mediolateral adjusting screws *G* Anteroposterior adjusting screws *H*, Adjustable connecting bar *I*, Lock nuts locking bar *H* *Z* Adjustable connecting bar assembly Note upper pins emerging through opposite cortex above and below lesser trochanter

tomical structures permit This facilitates reduction and gives greater stability

As in the case of all shaft fractures, the upper pin unit is applied first The first pin is placed in the channel of the

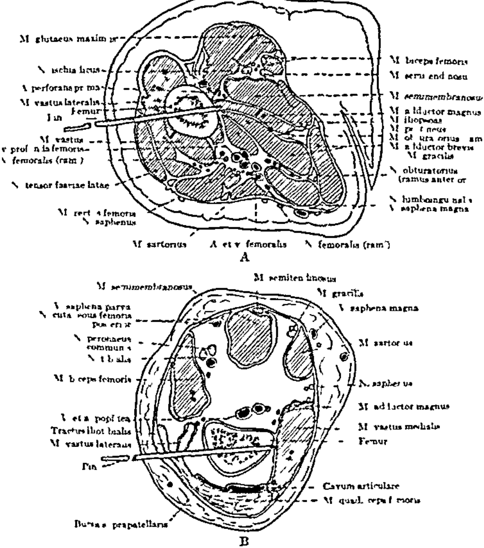


Fig 50.—A Section through upper third of right thigh upper surface showing insertion of pin. B, Section through right thigh 2 inches above condyles of the femur, upper surface showing insertion of pin

large pin bar and inserted directly through the skin to the trochanter of the femur one fingerbreadth from the tip of the trochanter The pin will easily pass through the cancel-

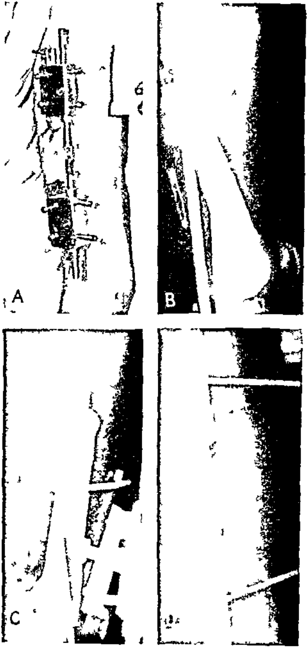


Fig 51

lous trochanter until it reaches the dense opposite cortex just above the region of the lesser trochanter (Fig 49) It must penetrate this cortex

Insertion of the first pin in the case of fracture at the junction of the upper and middle thirds must be guided by the fact that the upper fragment is abducted flexed and externally rotated In order for this pin to be inserted into the lateral surface of the upper fragment with the pin bar parallel to the fragment, the pin must be inserted from a slightly posterior angle and the pin bar held slightly flexed, abducted and externally rotated, so as to conform to the displacement of the fragment Before this first pin is inserted into the bone it is wise to check the amount of tension of the surrounding skin

The second pin is now placed in the channel of the pin bar and introduced through the skin to the bone as the pin bar is held *at least 1 inch* from the skin to allow for swelling which may be pronounced in fractures of the femur The apex of the convexity of the lateral surface of the fragment is determined by gently feeling out the arc of its circumference with the point of the pin When properly placed, the second pin will penetrate the opposite cortex a short distance below the lesser trochanter

After the introduction of the pins in the upper unit they are locked in the pin bar by means of the set screws By grasping the pin bar, the surgeon now has complete control of the upper fragment

The third pin to be inserted is the one nearest the knee joint and precautions must be taken to make certain that this important structure is not invaded The pin is inserted through the lateral surface of the distal fragment about one fingerbreadth above the condyle Before inserting pin number three, the following conditions should be carefully checked

1 The position and displacement of the distal fragment

Fig 51 —Transverse fracture of midshaft of femur Patient ambulatory ten days after reduction *A* Splint applied to the lateral aspect of the thigh. *B* X rays before reduction *C D* X rays after reduction

should be ascertained, so that the pin bar may be placed parallel to it

2 The length of the lower fragment and the thickness of the soft tissues should be checked, so that the proper size pin bar is used The regular short pin bar for the distal femoral fragment is applicable only in thin individuals and in the case of short fragments It is better in heavier patients to use the same size pin bar as the one used for the upper unit

3 The distal fragment and lower leg should always be lined up before inserting the distal pin unit This is easily done by drawing a line from the anterior superior iliac spine through the center of the patella to the interval between the first and second toes It is often opportune to line up the injured with the uninjured extremity with the pelvis level in doubtful cases By properly lining up the distal fragment, the major rotational displacement of the distal fragment will have been corrected and the maximal mechanical advantages of the splint assured

4 In fractures at the junction of the lower and middle thirds of the femur or in the supracondylar fractures of sufficient length, the knee should always be flexed to relax the gastrocnemius muscle and facilitate the application of the splint as well as the reduction of the fracture

In order to determine the correct position on the apex of the convexity of the lateral surface of the bone for inserting the pins as well as to determine the level of the fracture site, it is often advantageous to probe the bone with a long hypodermic needle

Every precaution for inserting the pin units should be meticulously followed in fractures of the femur because the stresses and strains for reduction and fixation are greater than for any other bone The pin units are the foundation of the splint and unless properly applied no form of external fixation can be successful A single pin injudiciously inserted may ruin an otherwise successful operation, and it is

far better to remove the improperly placed pin immediately and reinsert it properly than to risk ultimate failure of the treatment

As in the case of the upper pin bar, the distal pin bar must also be held *at least* 1 *inch* from the skin to allow for reactionary edema When both pins have been placed

A B C

Fig 52—Compound fracture of shaft of femur *A* Splint applied to lateral aspect of thigh Note lack of swelling and edema. Wound healed *B* X rays before reduction *C* X rays after reduction and application of splint.

through both cortices they are locked in the pin bar by the set screws as above The operator now has complete control of both fragments by grasping the pin bars

Application of the Connecting Bar Assembly and Reduction of the Fracture

Before applying the connecting bar assembly, it is best to reduce all major displacements of the fragments by hand Gradual traction is applied to the lower leg If time and circumstances permit or if the operator desires manual trac

tion may be applied until the muscles have become tired and are relaxed and then the major fragment displacement may be reduced by grasping the pin bars in either hand and carefully lining them up until satisfactory position is obtained The connecting bar assembly may then be applied and full reduction achieved by activating the various adjusting screws and the turnbuckle bar It is easier and usually more desirable however to obtain extension by means of the instrument itself The procedure recommended is as follows

1 The pin bars are grasped in each hand and the fragments are gently lined up In fractures of the lower shaft, it is advisable to flex the knee over the table
2 While the operator holds the fragments in alignment by means of the pin bars an assistant applies the connecting bar assembly and tightens all adjusting screws by hand The fragments are now fixed except for rotation which is permitted by the motion of the turnbuckle bar If no further reduction is desired at this time and the surgeon desires only to immobilize the fracture in good alignment the lock nuts of the turnbuckle bar are securely tightened with two wrenches and all adjusting screws snugly tightened against each other with wrenches Finally the nuts connecting the pin bars to the connecting bar assembly are tightened The splint is now secure and the fracture immobilized If complete reduction is desired the following steps are added
3 While an assistant holds the lower extremity in proper alignment so as to prevent rotational displacement during traction the operator activates the turnbuckle bar to obtain the desired amount of traction This may be roughly measured by the number of threads on the turnbuckle Traction by means of the turnbuckle should be performed very slowly to tire the muscles and allow for their proper relaxation Excess traction or overextension is dangerous so excessive force should never be applied to the wrench activating the turnbuckle In fact in most

cases sufficient traction may be obtained by turning the turnbuckle by hand after the muscles have tired

4 After the shortening has been reduced by sufficient but not excessive traction, full correction of the laterally displaced fragments is now obtained by turning the various adjusting screws As one adjusting screw is tightened the corresponding screw must first be loosened This is necessary because the adjusting screws tighten and lock against each other If this is not observed the pin bar may bend or break All movements of the fragments by means of the adjusting screws should be performed easily without the use of force If the adjustment appears difficult, the fragments are not gliding past each other as they should, but probably impinging on each other Further attempts at forcing the adjustment will produce either additional fracturing of the bone or unnecessary strain on the instrument

5 After the shortening and lateral displacement of the fragments have been corrected the fragments, in case of *transverse* fractures, are impacted or firmly apposed This is performed by gently activating the turnbuckle with a wrench The fragments are easily felt as they approximate each other When this is completed the splint is made rigid as described above

Spiral fractures of the shaft of the femur, as well as the *irregularly oblique* variety, may be as difficult to manipulate and reduce by external fixation as by any other method It is mechanically difficult in these cases, even under direct vision during open reduction, to bring the apposing surfaces of the fractured fragments together When treating this type of fracture it may be well to follow the following procedure

a Obtain sufficient length with the turnbuckle but do not lock rotation by locking the turnbuckle bar

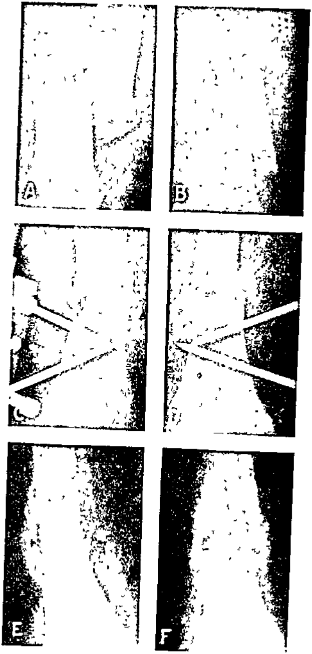


Fig. 53.

b While an assistant supports the lower leg, preferably with the knee flexed over the table, loosen all adjusting screws which control the *pin bars to their maximum extent*

c Proceed to manually manipulate and adjust the fragments They may often be felt to slip into place after the first manipulation If pointed fragments are entangled in the surrounding fascia they often slip free by gently rotating the fragments *In every case, it is necessary to* have the proper amount of traction With the added advantage of the ability to rotate either fragment on the turnbuckle most shaft fractures may be successfully reduced

Accurate reduction in irregular spiral fractures is not always necessary Perfect functional results are obtained if good alignment without shortening can be held until firm bony union has occurred

In *compound* fractures, the fragments are usually reduced under direct vision This situation is ideal for the employment of the splint because under direct vision the fragments may be easily manipulated by means of the adjusting screws until exact anatomical reposition of the fragments is accomplished This can be done with safety to the patient *since the fragments are not handled or manipulated* in the wound The fact that no additional immobilization such as the application of a plaster spica is necessary, creates an immediate postoperative condition which is not only ideal for the patient in *that it decreases the operative time but also for the* surgeon who is spared a lot of unnecessary work as well as making his services available for the care of other casualties

---

Fig 53.—Supracondylar fracture of femur with marked downward displacement of the distal fragment. *A B* X rays before reduction *C D* X rays after reduction and application of the regular femoral splint. Note that the pins grasp the lower fragment sufficiently to permit a good purchase The pin bar is held at a distance from the skin The pins do not penetrate the knee *F F*, Final x rays

Postoperative Care in Fractures of the Shaft of the Femur

Whether simple or compound, all fractures of the shaft of the femur should be considered serious, and proper treatment of shock instituted The leg should be elevated in a comfortable position with the knee slightly flexed Immediately after the application of the splint and the return to bed unless hemorrhage and progressive swelling contraindicate movement, the patient should be encouraged to move his toes and ankle to improve the circulation of the extremity Unusual pain which necessitates the use of morphine after the first twenty four hours should make the operator suspicious of infection, progressive hematoma formation causing fascial distention or thrombophlebitis When the latter condition is suspected a paravertebral sympathetic injection of 30 cc of 0 5 per cent procaine is given in either the second or third lumbar segment or both The injection may be repeated in three or four hours which is usually all that is required The pain incident to thrombophlebitis disappears immediately after the injection and the swelling usually subsides in twenty four or forty eight hours The prophylactic use of this simple injection in severely comminuted femoral shaft fractures, following the application of the splint, is suggested

Care of the Pin Sites—A sterile dry gauze protective dressing is used as long as necessary The skin about the pins is not rubbed and injudiciously swabbed with antiseptic solutions because this tends to loosen the skin from the pin and violates nature's protective reaction A light spray of one of the sulfa powders is a convenient treatment for the pin sites but its use should not be continued over a long period of time Bulky dressings which tend to irritate and macerate the surrounding skin should be avoided

Length of Bed Rest—Depending upon the individual case the patient should remain in bed until the reaction of the trauma has subsided In the average case this will be about two to three weeks Active and passive motion of the joints are encouraged as soon as the general and local conditions permit, the sooner the better If after the application of the splint, the knee is passively flexed so as to split the iliotibial

band structure, the knee motion may be somewhat more free

Length of Immobilization —Generally speaking, the splint should remain until firm bony union has occurred In the average femoral shaft fracture this will require from four to six months Periodic check x rays are taken to determine the amount of callus as well as the position of the fragments After removal of the splint in cases where union is not firm enough for weight-bearing, it is advisable to apply a protective plaster cast or splint during the early stages of weight-bearing

Transverse fractures of the shaft of the femur should be anatomically reduced, well impacted, and immobilized for at least six months in the splint If the splint is removed before six months, there is danger of secondary displacement of the fragments even though the fracture appears firm When plaster cast immobilization is used in conjunction with treatment by external skeletal fixation, and the splint is removed before six months, great care should be taken in the application of the plaster cast which should extend from the ribs to the toes on the involved side, and include the thigh of the opposite side The patient should be handled with extreme care during the interval between the removal of the splint and the application of the cast Poor results in the treatment of transverse fractures by external skeletal fixation are chiefly due to inaccurate reduction, failure of proper impaction, nonrigid and interrupted fixation, and immobilization for too short a period of time It takes at least six months for firm bony union in these cases The interposition of soft tissues as a reason for delayed and non union in these cases can be explained by the fact that the osteoid tissue between the fragments is injured and fibrosis of the osteoid tissue results

Necessity for Controlled Impaction in Transverse Fracture —The most common and serious complications of transverse fractures of the femoral shaft are delayed union and nonunion Their incidence is especially high in treatment by external fixation because of the mechanical distraction of the fragments which prevents the heavy thigh muscles

from bringing the bone ends in apposition There is also the added factor of bone absorption at the fracture site Many have failed to appreciate the extent of this bone absorption which occurs in some fractures Controlled impaction of transverse fractures should be routinely performed about the tenth and twentieth days The turnbuckle may either be activated by hand or by means of the wrench, and the impaction of the bone ends or preferably, the firm apposition of the bone ends, may easily be felt The amount of impaction may be determined by the threads of the turnbuckle as well as by the feel In every case the leg must be held in alignment by an assistant during the operation so as to prevent rotational displacement. After impaction, all lock nuts of the turnbuckle bar must again be securely tightened

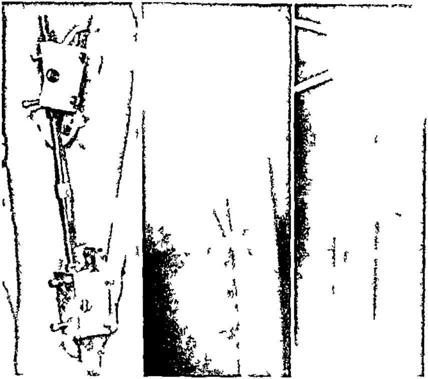
Maintaining the Rigidity of the Splint during Immobilization—All lock nuts and adjusting screws must be examined from time to time during the entire period of immobilization and those that may become loose which is very unusual, tightened This insures the constant stability of the splint

SUBTROCHANTERIC FRACTURES OF THE FEMUR

Fractures of the subtrochanteric region are hard to manage by external skeletal fixation Satisfactory rigid fixation of the femur in this region may be obtained by applying a right-angled pin unit to the trochanter and a second pin unit to the lateral surface of the lower shaft of the femur and bridging the bars by the external adjusting bar assembly (Fig 55) This method of application of the splint permits some adjustments of the fragments as well as impaction and is applicable also to operative procedures in the subtrochanteric region (Fig 56)

The first pin is placed through the hole in the right-angled pin bar and drilled through the trochanter in its anterior surface about three fingerbreadths distal to the anterior superior iliac spine (Fig 55) The second pin is passed through the opposite arm of the bar and drilled through the lateral surface of the trochanter at right angles to the first pin The pins are then locked in the bar The lower pin unit

is applied to the lateral surface of the lower end of the femur using the technique as set forth previously After the major displacement has been corrected by hand the exter



A B C

Fig 54—Spiral subtrochanteric fracture of the femur in a patient with tabes dorsalis Note the absorption of the head and neck of the femur and displacement of the trochanter above the acetabulum Lengthening of the femur was accomplished by activating the turn buckle after the application of the splint. Fracture healed in normal time Function of leg better than before fracture as a result of added leg length obtained

A Photograph of patient with splint applied *B* X rays before reduction *C* X rays after reduction Note lengthening of the femur obtained by activating the turnbuckle The regular femoral splint was used in this case Note small grasp of trochanter by the converging pins

nal bar is applied and secured. Rigid fixation of the bone is obtained without the use of plaster and allows motion of the knee and hip

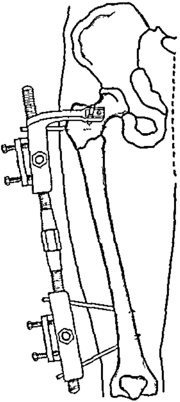


Fig 55—Diagrammatic drawing of special application of the femoral splint in the treatment of subtrochanteric fractures of the femur Note right angled pin unit for upper fragment, one pin inserted anteriorly and one pin laterally through the trochanter The regular pin unit is applied to the lateral surface of the lower third of the femur The adjustable connecting bar assembly connects the pin bars on the lateral surface parallel to the shaft of the femur Lock units on turnbuckle bar are not shown

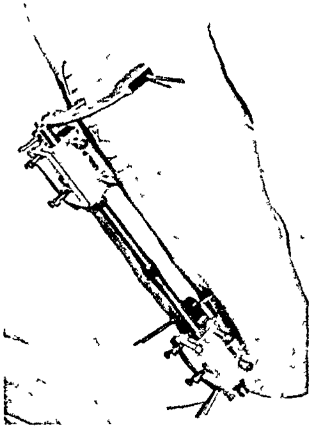


Fig 56—Application of the femoral splint with the right angled pin bar for the upper fragment, in the treatment of subtrochanteric fractures of the shaft of the femur. This application gives rigid fixation without plaster support. In this case, a high subtrochanteric osteotomy was performed

Fig 57

FRACTURES OF THE PELVIS

In certain severe fractures of the pelvis it is often desirable to apply lateral traction to reduce the fracture, as well as to maintain reduction. This may be accomplished by inserting a half-pin unit in the lateral surface of the trochanter of the femur for traction purposes (Fig. 57). This application is suggested whenever lateral traction on the upper femur is desired.

Fig. 57.—Multiple fractures of the pelvis with upward displacement of the right side, fracture and inward compression of the sacrum and sciatic paralysis. Rubber catheter in bladder

A, Before reduction *B*, After reduction and application of lateral traction by means of a regular femoral half-pin unit applied to the lateral surface of the upper end of the femur. Note the distraction of the sacroiliac joint. *C*, Distraction of sacroiliac joint corrected after proper adjustment of traction

CHAPTER XIV

FRACTURES OF THE TIBIA AND FIBULA

In fractures of the fibula and malleoli and of the tibia without displacement a properly applied unpadded plaster cast is sufficient In fractures of the tibia with displacement we prefer external fixation We have been using the Stader reduction and fixation splint for about eighteen months, during which period forty-seven fractures of the tibia have been treated by this method The results have been uniform and better than with any method we used in the past

External skeletal fixation is ideal for fractures of the shaft of the tibia, especially those that are compounded, comminuted, or associated with severe soft tissue injury In transverse fractures, which so often are the cause of delayed union or nonunion, and in extensive fractures with loss of bone substance, the splint is of special merit In such cases the normal length of the leg is maintained until healing is well established and reconstructive surgery has been accomplished

CLASSIFICATION OF FRACTURES OF THE TIBIA AND FIBULA FROM THE STANDPOINT OF TREATMENT BY EXTERNAL SKELETAL FIXATION

A Acute fractures—simple and compound
1 Fractures with long proximal and long distal fragments (Figs 57*a*, 58, 59)
2 Fractures with short proximal and long distal fragments (Fig 63)
3 Fractures with long proximal and short distal fragments (Figs 61, 62)
4 Fractures with short proximal and short distal fragments (Fig 64)
5 Fractures with long proximal and comminuted dis-

tal fragments (no major distal fragment) (Figs 65, 66)

6 *Fractures with short proximal and comminuted distal fragments* (Fig 67)

B *Compound fractures with osteomyelitis*

C Old ununited fractures with or without loss of bone

D Old ununited fractures with chronic osteomyelitis

E Old fractures with malunion

APPLICATION OF THE SPLINT TO THE VARIOUS TYPES OF ACUTE FRACTURE OF THE TIBIA AND FIBULA

Fractures with Long Proximal and Distal Fragments

Fractures with long proximal and distal fragments comprise by far the great majority of fractures of the shaft of the tibia and require the use of the regular tibial splint (Figs 57*a*, 58, 59).

Sites of Splint Placement —The site of election is on the anteromedial surface of the tibia However, it may be necessary in certain circumstances, such as in wounds of the anterior surface, to place the unit on the anterolateral or medial surface, as the case demands

Pin Placements —The first pin (pins are $^3/_{16}$ inch in diameter and 5 inches long) is inserted directly through the skin about one or two fingerbreadths from the upper end of the tibia just medial to the tibial tubercle During the insertion of this first pin, the pin bar much be held parallel to the proximal fragment, because the greater the antiparallelism between the pin bars and their corresponding fragments, the greater the restriction of the reduction maneuvers

When inserting the second pin in the center of the shaft, the pin bar should be held about ½ inch from the skin so as *to allow for any secondary swelling should it occur* The pins are then locked in the pin bar by means of the set screws

The third pin is now inserted in the distal fragment about *two fingerbreadths from the lower end of the tibia* just medial to the tibialis anticus tendon, it being again made certain that the pin bar is held parallel to the distal frag-

ment Again when inserting the fourth pin, the pin bar is held about ½ inch from the skin and when applied properly, the pin bars will not only be parallel to their respective fragments but will be parallel to each other when the fragments are properly lined up

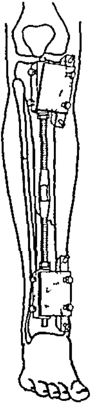


Fig 57a.—Diagrammatic drawing of the regular tibial splint as applied to the anteromedial surface of the tibia

Application of the Adjusting Assembly—The surgeon now grasps each pin bar and manually corrects the major displacement of the fragments including the rotation by bringing the distal fragment in line with the proximal This alignment can be readily checked by a line drawn from the anterior superior iliac spine through the center of the

patella to the interval between the large and second toe. When there is a question about proper alignment, the injured side can be compared with the uninjured side.

While the surgeon holds the pin bars in their corrected positions, an assistant applies the external adjusting apparatus as described previously.

Reduction of the Fracture.—As stated above, most of the major correction, including the rotational displacement, is corrected by hand, before the adjusting assembly is connected to the pin bars. Complete reduction may now be performed or delayed for several days as the circumstances demand; for example, in transverse fractures associated with extensive soft tissue injury or in badly comminuted fractures immediate full extension may not be advisable, and in cases of multiple casualties the time factor may not permit immediate individual reduction. In such cases, by a simple tightening of the screws and lock nuts, the unit will act as a rigid splint, the secondary adjustments or reduction maneuvers being performed later, often without the need of an anesthetic and with or without fluoroscopic control. The actual reduction afforded by the various adjusting screws has already been described.

In the reduction of the fracture it is well to keep in mind the following points:

1. Lateral displacements cannot be corrected before the shortening has been corrected.

2. Overextension damages the soft tissues and is dangerous. Because this mechanical splint with its powerful turnbuckle exerts such tremendous force with such ease we must become imbued with a spirit to save the soft tissues and never use force.

3. If at any time during the reduction maneuvers it seems to be necessary to use force, stop, loosen all adjusting screws and lock nuts, and start over again. In some cases it is better to remove the entire adjustable connecting bar assembly.

4. If the limit of the adjustment reduction has been obtained without having achieved adequate reduction of the fragment, it is best immediately to remove the improperly

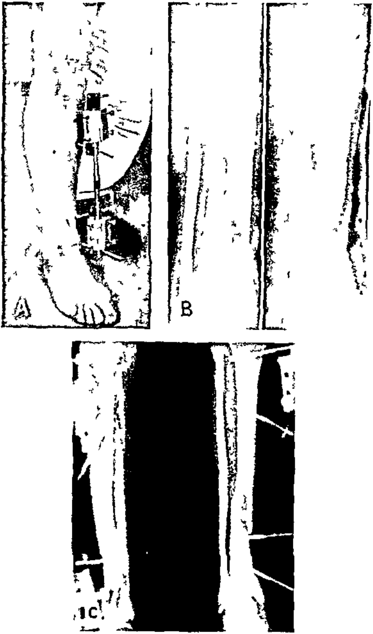


Fig 58

placed pin and to reinsert it with the pin bar in the proper place

5 Pins must be inserted through the opposite cortex

6 In spiral fractures of the tibia when difficulty is encountered in the reduction maneuvers of the splint, it is advisable to use straight traction on the leg for fifteen to thirty minutes followed by hand manipulation of the fragments through the medium of the pin bars before applying the connecting bar assembly If this is unsuccessful soft tissues are probably interposed between the fragments and should be surgically removed

Fluoroscopic and X ray Control for Pin Insertion and Reduction —The pins may be accurately inserted from cortex to cortex without the aid of the fluoroscope It is usually easy to feel the pin go through each cortex As a rule it is better to insert the pins a little too far because later they may be easily pulled back with the hand chuck if the check x ray films show them to be too far in

It is also preferable, as a general rule, to guide one's reduction maneuvers by the anteroposterior and lateral x ray films rather than by the fluoroscope One should train himself to visualize accurately not only the fracture displacement but also the mechanisms of the splint and the forces to be overcome in order to effect proper reduction of the displacement The dangers of excessive irradiation to the surgeon are well known but not sufficiently acknowledged

Check X-rays and Secondary Adjustments —Depending upon the type of fracture check x rays are taken from time to time to determine not only the presence of callus formation but also the position of the fragments and the necessity for secondary adjustments In cases of transverse fractures, gentle controlled impaction should be performed

---

Fig 58.—Regular tibial splint applied to the anteromedial surface of the leg for a spiral fracture of the tibia at the junction of the middle and lower thirds Patient had been treated by transfixation with pins in plaster

A Showing application of splint to anteromedial surface of tibia *B*, Prereduction x rays Note transfixation pins in plaster and poor reduction. *C*, Postreduction x rays

Fig 59

about the tenth and twentieth days to prevent delayed or nonunion

Length of Immobilization in the Splint—Immobilization should be continued until firm bony union has occurred The progress of union can be ascertained by simply removing the external adjusting assembly and testing by hand If firm union has not occurred the assembly is immediately replaced The period of immobilization will vary with the individual and the type of fracture As a general rule, the earlier and more constant the weight bearing in the splint,

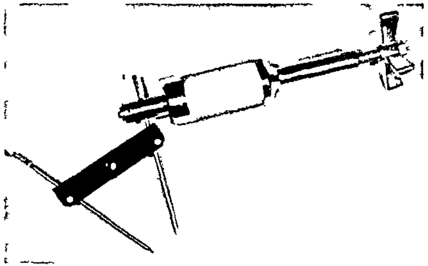


Fig 60 —Special pin cutter to cut excess pin length

the earlier the union One should therefore strive for early and continued weight bearing in the ambulatory patient

It may sometimes become necessary to remove the splint before firm bony union has occurred, for example upon premature discharge from treatment or when the splint is required for another patient It may, therefore be stated that the splint will have satisfactorily accomplished its pur

Fig 59.—*A* Regular tibial splint applied to the medial surface of the leg for a comminuted spiral fracture of the midshaft of the tibia. Excess pin length is removed by pin cutter (see Fig 60) *B* Prereduction x rays. *C* Postreduction x rays.

pose if it is allowed to remain for the length of time one would otherwise use continuous traction or transfixation in plaster, that is, from six to eight weeks A plaster cast with incorporated walking caliper may then be used as an adjunct to treatment

Fractures with Short Proximal or Distal Fragments

With a fracture of the shaft of the tibia in which there is a short proximal or distal fragment that will not allow

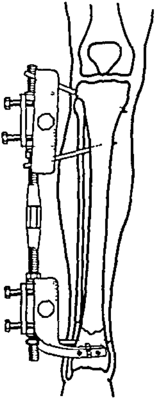


Fig 61.—Diagrammatic drawing of the tibial splint as applied to a short distal fragment. Note special right-angled pin unit.

the converging pins of the regular tibial pin bars to satisfactorily engage the fragment, a special right angled pin bar is used (Figs 61, 62, 63) The pins in the right angled

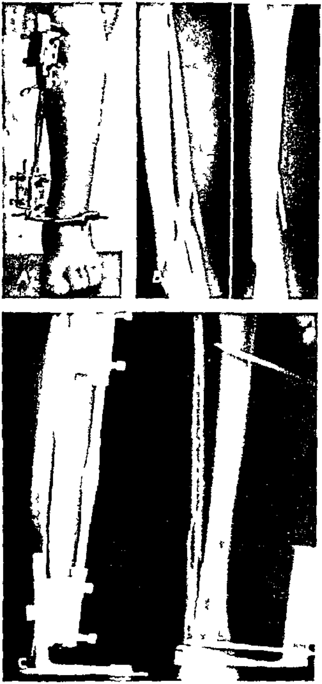


Fig 62 – 4, Application of the splint with right angled pin bar to a comminuted spiral fracture of the lower end of the tibia Note that the lower pins have been inserted on either side of the extensor tendons B, Preoperative x rays. C Postreduction x rays

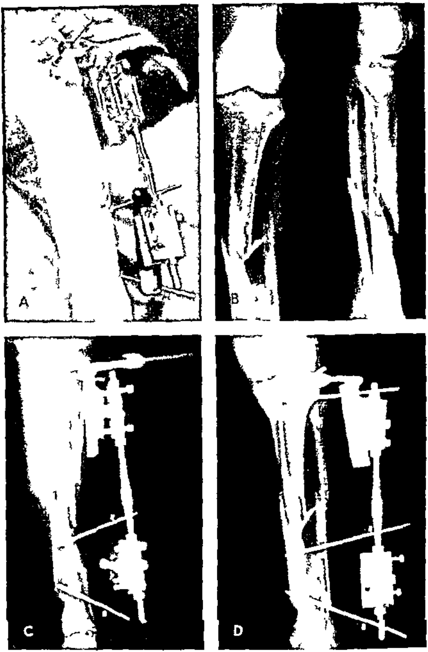


Fig 63 —*A* Application of the right angled pin bar in the case of a short proximal fragment The splint was applied to the lateral aspect of the leg in this case because it was necessary to transfix the lateral condyle of the tibia with one of the pins of the right angled pin unit. It is usually more desirable to apply the splint to the anteromedial surface of the tibia *B* Prereduction x rays. Severely comminuted extensive fractures of the upper and midshaft of the tibia. *C D* Postreduction x rays anteroposterior and lateral Note old healed fracture of lower shaft of the tibia

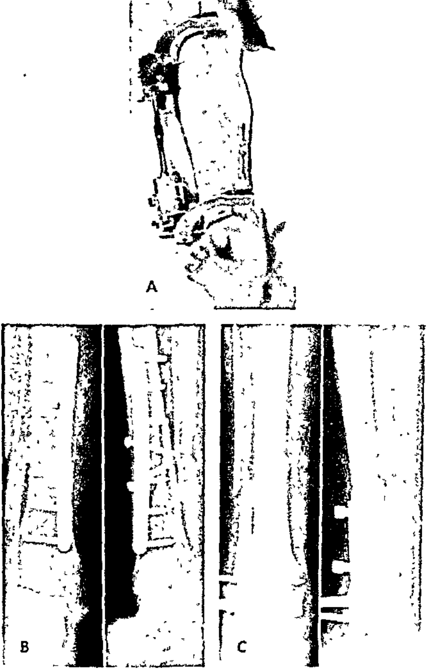


Fig. 64.—*A*, Application of splint with double right-angled pin units in the case of extensive fractures of the shaft of the tibia with short proximal and short distal fragments. Splint applied to the lateral aspect of the leg because of the compound fracture wound of the medial surface. *B*, Prereduction x-rays. *C*, Postreduction x-rays

pin bar pass through the bone from cortex to cortex at right angles to each other and will therefore allow one to engage a fragment as short as 1½ or 2 inches In the lower fragment the pins are inserted in the anteromedial and anterolateral surfaces so as to avoid penetrating the extensor tendons or their sheaths and also to permit the splint to be applied to the anteromedial aspect of the leg Before applying the right angled bar one should place it on the desired aspect of the leg and visualize the position in relation to the splint as a whole The bar portion of the right angled pin bar must also be held parallel to the fragment during the insertion of the pins and also parallel to the pin bar of the main fragment This is necessary to obtain the maximum amount of reduction by means of the various adjusting screws as described

Comminuted Fractures of the Distal End of the Tibia

It is obviously impossible in comminuted fractures of the distal end of the tibia to apply either a regular tibial splint or one with a right-angled unit attached as previously described It is necessary to transfix the fractured leg from the proximal fragment to the os calcis and this is accomplished by applying a right-angled pin bar unit to the os calcis in such a way that one pin is inserted transversely through either the lateral or medial surface from cortex to cortex and the second pin is inserted in the posterior aspect of the os calcis just distal to the insertion of the Achilles tendon passing longitudinally into the body of the os calcis for a distance of about 1½ or 2 inches (Figs 65 66 67)

Before attempting any reduction maneuvers in these cases it is essential to obtain proper extension by slowly activating the turnbuckle When the check x ray films show that the astragalus has been properly distracted from the main proximal tibial fragment one can usually replace the distal fragments by hand The function of the splint in these cases is to

1 Line up the main proximal fragment with the astragalus and foot

2 Distract the main proximal fragment from the astragalus so as to make sufficient space for reposition of the displaced *comminuted distal fragments* The ligamentous at

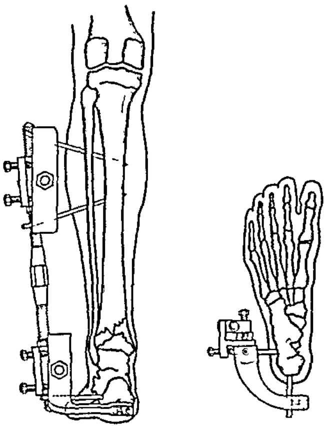


Fig 65—Diagrammatic drawing of the application of a right angled pin unit to the os calcis. One pin is inserted through both cortices *of the os calcis from its medial or lateral aspect and the second* pin penetrates the posterior aspect of the os calcis for a distance of 1½ *or 2 inches This method of splint application is used for com*minuted fractures of the distal end of the tibia (no major distal fragment) *A regular half pin unit or a right angled unit may be used* in the proximal fragment.

tachments still adherent to the *fragments* will very often spontaneously reduce the major displacements with proper controlled distraction which is afforded by this splint.

Fig 67

Fig 67.—*A*, Application of the splint in the case of extensive fractures of the entire tibial shaft with a short proximal and no distal fragment. *A right angled pin unit is inserted in the proximal fragment*, and a right angled unit in the os calcis. The adjustable *connecting bar assembly connects the two right angled pin bars*. A plaster cast is required to support the central shaft fragments In this case there were multiple compound fractures of the entire shaft of the left tibia with marked dislocation and disruption of the ankle joint. There was also a trimalleolar fracture with dislocation of the ankle on the right side The splint was applied immediately after injury and while the patient was receiving plasma for shock Local anesthesia was used and a thorough débridement was performed and the wounds lightly packed with vaseline gauze after the implantation of sulfanilamide The wounds healed without infection Union of the tibia was obtained in good position and alignment. *B*, Preoperative x rays (3 pictures) showing extent of fractures and dislocation of the ankle joint. *C*, Postreduction x rays, anteroposterior and lateral

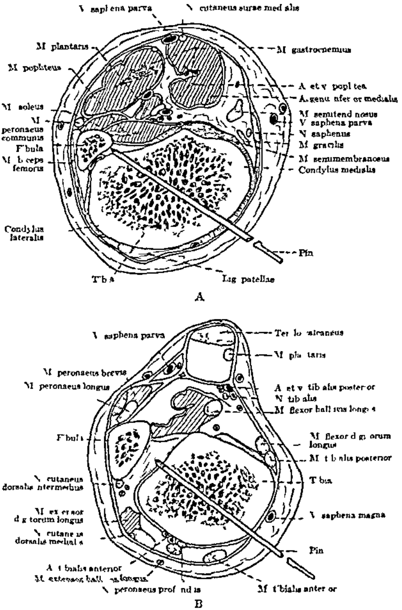


Fig 68—*A* Section through head of right fibula upper surface showing insertion of pin *B* Section 2 inches above lower end of right fibula upper surface showing insertion of pin

INCIDENCE OF FRACTURES OF THE LOWER LEG

Fractures of the tibia and fibula are more common in the Navy and Marine Corps than fractures of any of the other long bones of the extremities (see Tabulation); compound fractures are more frequently observed in the tibia and fibula and the incidence of being invalided from the service is higher for fractures in this region.

TABULATION

NUMBER OF FRACTURES OF LONG BONES OF EXTREMITIES IN THE UNITED STATES NAVY, 1940

Bone	Simple	Compound	Total
Fibula	184	2	186
Tibia	89	19	108
Tibia and fibula	84	21	105
Radius	182	1	183
Ulna	54	4	58
Radius and ulna	28	5	33
Humerus	44	6	50
Femur	42	7	49

NONUNION AND DELAYED UNION AS FACTORS IN POOR RESULTS

Nonunion and delayed union are more commonly associated with the transverse fractures of the lower third of the tibia than with any other type of fracture. Failure of bony union, according to the statistics of Bruns, occurs in 0.5 per cent of all cases. Scudder, on the other hand, finds an incidence of nonunion of 2 to 3 per cent and Hey Groves of 4 to 5 per cent. Henderson at the Mayo Clinic found that of 211 cases of pseudo-arthrosis in which operation was done, 66 per cent were due to fixation by plates and screws. Scudder found that in 70 per cent of thirty-two cases pseudo-arthrosis resulted from the same cause.

In the transverse fractures of the lower third of the tibia, callus forms slowly because the medullary cavity presents a small opening, because the transversely torn periosteum is not separated from the bone, because of the poor blood supply and frequent injury to nutrient vessels in this region, and because the tibia has no muscle covering on its

anterior or medial aspect It requires ten to twenty weeks for union to become firm Callus forms on the posterior and lateral aspects only Owing to poor blood supply, inflammation in the lower leg is always slow to respond to treatment

Poor treatment is more often the cause of delayed union and nonunion than is the injury itself The following should be considered as *contributing causes* of delayed union and nonunion

1 Interposition of soft parts
2 Faulty position of the fragments
3 Frequent interruption of fixation
4 Too brief fixation
5 Distraction of fragments by too strong traction
6 Multiple fractures of the shaft
7 Fracture of tibia with the fibula intact
8 Constant moving of the fragments upon one another
9 Infected fractures without adequate drainage
10 Extensive removal of fragments in comminuted open fracture
11 Internal fixation by plates and screws
12 Lack of fixation as in congenital fractures
13 Massage and passive movements of fractures
14 General disease—such as, gumma, carcinoma, sarcoma, osteomyelitis tuberculosis osteomalacia and rickets

CLINICAL ANALYSIS

1 All oblique fractures unite much more rapidly than the transverse type The average period of immobilization of oblique fractures was eighty three days, and of transverse fractures 157 days

2 Four severely compounded fractures of the tibia responded to treatment with the Stader splint in a manner similar to that of the simple type

3 The splint may be applied several days after fractures occur, and satisfactory results may be obtained without open reduction In one case the splint was applied fourteen days after the fracture, and in another thirty-four days after the fracture The men were restored to duty without any disability (See Figs 69, 70)

4. By means of the Stader splint all fractures were reduced and maintained in the desired position without any difficulty.

5. No infection occurred about any of the pin sites. The average period of healing of the sites was six days (Fig. 70, *D*). In only two cases was there a delay in healing, in one case fourteen days and in the other twenty days. This delay in healing was about one pin site only in each case.

6. Bone reaction to pins was that of a very slight periosteal thickening about a few pin sites. No sclerosis about pin sites or osteomyelitis was seen.

7. All patients had complete motion in knees and ankles in an average of five days after application of the splint. No physical therapy was required in any case.

8. All patients other than those with associated injuries became ambulatory (using crutches and partial weight-bearing) the day following the application of the splint.

9. By means of external fixation patients are restored to duty much earlier than those successfully treated by internal fixation. (See Fig. 71.)

10. Cases of acute or chronic osteomyelitis following infection after internal fixation are being treated successfully by Stader splint after removal of the plates and screws and thorough saucerization. (See Fig. 70.)

11. Transfixation pins incorporated in plaster are not always a successful method either for reducing the fracture or retaining it in proper position. Two patients admitted after the fracture fragments were not properly reduced by this method elsewhere had the cast and transfixation pins removed and a Stader splint applied. Reduction was easily obtained and maintained. (See Figs. 69, 70.)

12. The Stader splint is ideal for treatment of comminuted fracture of the tibia where accuracy of reduction is essential to avoid impaction or distraction. (See Fig. 67.)

13. Multiple fractures of the shaft, whether simple or compound, are amenable to this method of treatment, which is better than any other method that we have tried. (See Fig. 67.)

14. In old fractures with considerable loss of substance of

A B C

Fig 69 (E S).—Simple oblique fracture of tibia right leg distal third with comminuted fracture of proximal third of fibula *A* Before reduction *B* After reduction *C* Ten weeks after application of splint

CASE REPORTS

E S (see Fig 69), aged fifty-three years, on September 9, 1942 suffered an injury consisting of a simple oblique fracture of the distal third of the right tibia and a simple comminuted fracture of the proximal third of the right fibula He had two-pin transfixation and cast *with unsatisfactory reduction elsewhere* Cast *and pins* were removed October 6 and a Stader splint was applied October 26, thirty-four days after the injury The patient was out of bed by November 6, with partial weight-bearing on crutches Full weight bearing began December 1, and the splint was removed December 22, 1942 Firm union resulted Total immobilization with the splint occupied *seventy-seven days* Because the patient had developed bronchopneumonia one week after injury and suffered the additional serious handicap of blindness, weight-bearing in this case was delayed

Final result: full function

A B C D

Fig. 70 (F S) —Compound fracture of tibia and fibula right leg with associated osteomyelitis A Before reduction B After reduction C Six months after injury D Showing condition of the pin sites immediately after removal of pins

E S (see Fig 70), aged fifty-three years, had previously suffered a compound fracture of the lower right leg on January 19, 1941, followed by osteomyelitis On March 10, 1942 he refractured the right tibia and fibula Previous treatment elsewhere consisted of two-pin transfixation and cast which resulted in unsatisfactory reduction The cast and pins were removed and a Stader splint was applied on April 14, 1942 The patient had chronic osteomyelitis with a draining sinus He was out of bed on crutches with partial weight bearing by April 16 The splint was removed July 1 Firm union had resulted, but a walking cast was applied which was removed on July 22, 1942 Immobilization in the splint had been maintained for seventy-eight days, and in the walking cast for twenty-two days, making a total of 100 days of immobilization

Final result firm unions, sinus completely healed

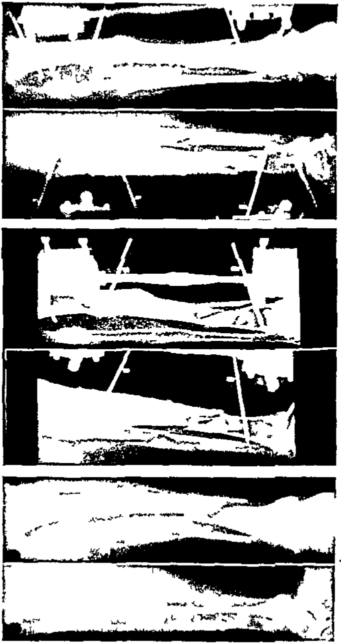


Fig 71 (E B) —Simple oblique fracture right leg distal third in tibia previously fractured and plated with fracture of middle th rd of fibula A Before reduction B After reduction C Five weeks after application of splint.

E B (see Fig 71), aged fifty-three years, had had a previous fracture of the tibia on July 23, 1940, which was plated elsewhere He returned to work eleven months later On December 12, 1942, he suffered a simple oblique *fracture of the distal third of the same tibia and a fracture* of the middle third of the fibula A Stader splint was applied December 18 and partial weight-bearing with crutches began the next day Full weight-bearing was allowed February 1, 1943 X-ray on January 31, 1943, *shows very good union after a period of fifty days of im*mobilization with the splint

Final result firm union

tibia, where a bone graft must bridge a large space, the Stader splint is ideal for the firm implantation, fixation and set of the bone graft No sutures, screws, or other foreign bodies are necessary

15 In most cases it is desirable to remove the splint in eight to ten weeks and replace it with a nonpadded walking cast to complete the period of convalescence and firm union This will avoid unnecessary retention of the pins in the bone and render the splint available for use on other cases In certain cases it will be desirable to retain the splint for a longer period of time The judgment of the surgeon will determine the time factor

CHAPTER XV

FRACTURES OF THE OS CALCIS

Fractures of the os calcis present unusually difficult problems in reduction and restoration of function. The importance of these problems is growing with the increase in the number of such injuries not only in combat, but in men in training, on the athletic field and even on liberty. Airplane crashes, parachute jumping and explosions aboard ship are augmenting the incidence of these fractures. Explosions of mines or torpedoes against a ship lift the men off the deck and cause an injury in landing similar to that of a fall. Fractures of the os calcis are also sustained from deck vibrations caused by explosions or near misses. With this material increase in the number of os calcis fractures it *becomes the duty of the medical officers of the armed forces* to make every possible effort to expedite the return of these *casualties to duty*.

The first real scientific approach to a solution of the problems offered by this difficult fracture is credited to Lorenz Böhler and his associates, Vidal, Schneck and Ehalt, whose work became the basis of our present therapy. The principles as outlined by Böhler are generally well accepted and fulfill the basic requirements of fracture treatment in general, as attested by Hey Groves and Watson Jones. However, the application of these principles in the management of fractures of the os calcis is often difficult and impracticable, especially on board ship and in the field hospital where access to special reduction frames and fracture equipment is not available.

In the Böhler method, after proper reduction of the fractured os calcis, the position is maintained either by continuous traction or by transfixation in plaster with Steinmann pins through the os calcis and tibia. In either case, it requires the proper application of the nonpadded plaster cast

which even in experienced hands is a difficult procedure, and fraught with danger and serious complications when performed by the casual operator Treatment by continuous traction offers obvious objections on board ship, while in field hospitals it is often impracticable Treatment by transfixation in plaster is objectionable not only because of the difficulty in its application, but because (1) plaster is not a rigid immobilizing agent, especially where slight pin seepage is present, (2) plaster transfixation does not allow for secondary adjustments which to be made require the removal of the cast and replacement on the reduction frame This not only unnecessarily prolongs the primary operation, when the initial reduction was unsatisfactory, but adds to the morbidity where secondary adjustments are required

Kreuz suggested the application of the principle of the Stader fixation splint to a new splint to overcome these handicaps

A NEW APPROACH IN THE TREATMENT OF COMPRESSION AND COMMINUTED FRACTURES OF THE OS CALCIS

The exigencies of the service demand that we return casualties to duty as quickly as possible The treatment cannot be too complex or require cumbersome and intricate equipment The treatment must be universally adaptable to the average traumatic surgeon on board ship or in the field hospital, as well as in the well organized base hospital Although we agree with the advocates of delayed reduction in fractures of the os calcis, which allows us eight days to get the patient to a base or shore hospital, there will be times when the reduction must be performed on board ship or in a field hospital The treatment must conform to the basic requirements governing the treatment of fractures in general

We have developed a method of approach to this complex problem of os calcis fractures, in cooperation with Stader who designed an external reduction fixation splint (Fig 72, *A*), which we have used in nine cases at the United States Naval Hospital, Philadelphia This apparatus permits not only *reduction* of the fracture, but becomes the splint

upon completion of the reduction. No reduction frames or plaster are required. The fixation is constant and rigid. The integrity of the subastragaloid joint is constantly maintained. The turnbuckles permit controlled tangential traction in either valgus or varus. The constantly controlled traction allows one to overextend and produce *sufficient space* into which the laterally displaced fragments may be *easily compressed, often by hand.*

Secondary adjustments may be made with ease and without sacrificing the position already obtained. Active motion of the knee and toes, and activity with crutches promotes earlier healing. With constant rigid fixation there is no pain or discomfort, and the general well-being of the patient is promoted.

ANATOMICAL CONSIDERATIONS

The spongy character of the os calcis with its thin outer cortex gives it a certain elasticity to withstand the stresses and strains of weight-bearing. Most of this weight is borne by the outer arch of the foot, consisting of the os calcis, cuboid and outer two metatarsals. In running and jumping, much of the jar is taken up by the so-called "spring ligament," or *inferior calcaneoscaphoid ligament*, which traverses the space between the sustentaculum tali of the os calcis and the inferior surface of the scaphoid, thus reinforcing and protecting this important articulation.

Lateral flexibility of the foot is necessary to allow one to walk on uneven surfaces and to absorb lateral thrusts on the foot, as for accommodation to the roll of a ship. This mobility is assured by the subastragaloid joint with its two important articulations, one posterior between the bodies of the os calcis and astragalus, and the other anterior between the astragalus, navicular and sustentaculum tali.

The posterior calcaneal articulation is large and rounded, with its convexity upward; the anterior is small and concave. Between these two articulations is the strong interarticular ligament which binds the adjacent talus and calcaneus together, and thereby helps to sustain the integrity of the subastragaloid joint space. The ability to stand on one's toes depends upon the activity of the gastrocnemius

muscle whose Achilles tendon is inserted into the posterior surface of the tuberosity of the os calcis The upper surface of the tuberosity runs obliquely downward from the edge of the posterior subastragaloid articulation, and lines drawn from this point anteriorly to the anterior rim of the anterior subastragaloid articulation, and posteriorly over the superior surface of the tuberosity, will bisect to form an angle of about 40 degrees This is the so-called *tuber-joint angle* of the os calcis, so essential in the evaluation of the pathology as well as the proper treatment of os calcis fractures

PATHOLOGICAL CONSIDERATIONS

Depending upon the anatomical integrity or viability of the bone itself, the os calcis fracture may vary from simple isolated fracture lines without displacement to various degrees of compression and comminution in the most serious of which the os calcis may be literally "smashed to pulp"

In every fracture of the os calcis the two most important considerations are the degree of the disparity of the tuber-joint angle and the extent of the involvement of the subastragaloid joint As a general rule the greater the disparity of the tuber-joint angle, the more extensive the compression and comminution, and therefore the greater the encroachment upon the subastragaloid joint space

The line of longitudinal fracture usually passes through the posterior articulation with various degrees of lateral displacement of the lateral portion, and there may be one or more perpendicular fracture lines running down through the inferior surface of the os calcis Normally, the weight-bearing lines of force pass through the medial side of the os calcis, and not through its center, and in walking there is a tendency to pronation of the os calcis sometimes aggravated by the pull of the gastrocnemius, especially in the flat foot

In fractures the inferior and lateral portions of the os calcis are generally displaced outward and upward This lateral bulge can readily be felt under the external malleolus Because of the upward displacement of the tuberosity,

the Achilles tendon is shortened and the tuber-joint angle decreased Depending upon the extent of comminution and transverse fracture lines, there is a greater or lesser degree of shortening of the os calcis produced mainly by the action of the short muscles of the foot The extent of shortening and compression can usually be discerned by palpating the medial surface of the os calcis and measuring the distance from the malleoli to the posterior inferior surface of the os calcis

The normal concavity of the medial surface of the os calcis will be destroyed as well as the normal varus position of the heel Further encroachment upon this concavity may also be produced by a medially displaced sustentaculum tali which may be fractured alone or in conjunction with severe comminuted fractures of the os calcis Occasionally the calcaneocuboid joint may be involved, usually by longitudinal fracture lines running into the joint. In severe fractures producing a displacement of the entire posterior articulation, one should look for a concomitant displacement of the astragalonavicular joint the head of the astragalus being tipped forward and usually rotated

THE DISABILITY IN BAD RESULTS

The chief complaints of the patient with a badly united fracture of the os calcis are pain limitation of lateral motion, and inability to run, jump or stand on the toes Where fracture lines have extended into the subastragaloid joint, causing hemorrhage and eventually fibrosis and irregularity *of the articular cartilage, the residual pain and disability* are usually proportionate to the accuracy of the replacement of the displaced fragments and the *maintenance of adequate joint space during the process of healing*

The normal subastragaloid joint space is large and well defined so as to allow for its peculiar motion, and the preservation of this space is important not only from the standpoint of proper functional restoration, but because the maintenance of this space during the reparative process permits better healing of the articular cartilage as well as the sub-

chondral bone The strong interosseous ligament will also heal more readily in its normal extended position with an adequately maintained joint space

The body can usually accommodate itself painlessly to mild irregularities in the articular surface of the subastragaloid joint provided there is adequate joint space whereas with restriction of joint space there is usually pain regardless of the regularity of the joint Secondary traumatic arthritic changes may develop regardless of any and all therapeutic procedures and may not appear for months or years after injury Abnormal dorsiflexion of the foot and weakness and inability to stand on the toes are due to a relaxed heel cord as a result of improper reduction of the disparity of the tuber joint angle and upward displacement of the tuberosity

Painful medial ligaments and traumatic pes planus in an otherwise well treated fracture of the os calcis are due in part to the alteration in the normal varus position of the os calcis in which the lines of force of the body are shifted more medialward on the os calcis producing a tendency to valgus of the hind foot With this abnormal valgus or pronation of the hind foot the insertion of the Achilles tendon is shifted laterally in relation to the weight bearing and the gastrocnemius tends to act as a pronator of the hind foot, thus increasing the flat foot

Another important factor producing pain after treatment for os calcis fractures is the *demineralization* of the bones as a result of prolonged immobilization We believe that this factor has not been sufficiently stressed It has occurred to us that possibly we have been immobilizing our os calcis fractures too long We have therefore been working on the principle of *minimal length of immobilization and early weight bearing* to prevent the extensive osteoporosis or demineralization which is general in os calcis fractures thereby decreasing the morbidity and painful disability from this cause

DIAGNOSIS

Proper x ray facilities may not always be available to the medical officer of the armed services and he may be

called upon in many instances to treat fractures of the os calcis without benefit of adequate x-ray films or their expert interpretation. It becomes necessary for him, therefore, to evaluate the case on hand by physical examination alone.

Any painful heel, whether traumatized directly by a fall *or indirectly by the effects of an underwater explosion on* board ship, should be regarded as a potential fracture of the os calcis. Local swelling and tenderness and pain on weight-bearing are constant findings. When there is any appreciable widening and comminution, the diagnosis may *often be made by observation alone.*

It is well, if only one heel is involved, to compare the injured with the uninjured side. In doing so, the thumb is placed along the medial concave surface, and the second, third and fourth fingers on the lateral surface, and the following facts are noted in each: (1) width of the os calcis; (2) the contour of the medial concave surface of the os calcis; (3) the smoothness and regularity of the lateral surface; (4) the extent of bulge of the lateral surface and encroachment of the normal space under the external malleolus; (5) the amount of shortening and compression, by noting the distances from the base of the heel in the cupped palm, the tip of the internal malleolus with the thumb and the tip of the external malleolus with the middle finger; (6) the degree of flattening or disparity of the tuber-joint angle, by the upward tilt of the tuberosity and flattening of the sole; (7) the extent of laxity of the Achilles tendon, by the abnormal dorsiflexion of the foot which may be easily *determined under anesthesia.*

When the proper x-ray facilities and interpretations of films are available, a thorough study of the os calcis should include proper plantar-dorsal and lateral exposures, as well *as views of the midtarsal joint.* X-ray views of the uninjured extremity should always be taken for comparison when possible, so as to have a concept of the patient's normal foot architecture, except in cases of obvious abnormalities.

APPLICATION OF THE SPLINT IN THE TREATMENT OF COMPRESSION AND COMMINUTED FRACTURES OF THE OS CALCIS

The reduction may be performed immediately or delayed until the primary swelling has disappeared Spinal anesthesia is the anesthesia of choice, 75 to 100 mg. of novocain

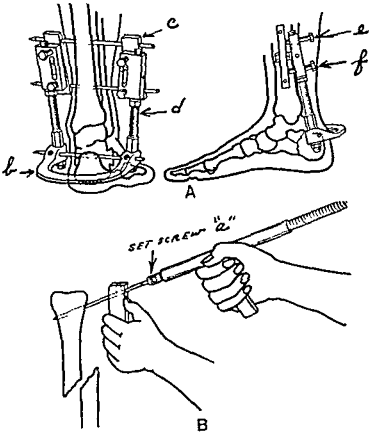


Fig 72—*A*, Os calcis reduction-fixation splint (Stader). *b*, U-shaped heel bar; *c*, pin bar; *d*, adjustable connecting bar; *e*, *f*, tangential adjusting screws; *B*, Flexible shaft hand-operated drill.

being sufficient in the average case. Both legs are prepared so that the width of the normal os calcis may be ascertained during the operation to check the amount of compression to be used on the injured member.

Insertion of the Pins

A stainless steel pin, $^3/_{16}$ inch in diameter and 6 inches long, is placed in the chuck of the flexible shaft hand drill (Fig 72, *B*) *and secured with the set screw* (*a*) It is then inserted in the U shaped bar (*b*, Fig 72 *A*) and drilled *transversely through the os calcis in its most superior posterior* portion just at the insertion of the Achilles tendon (Fig 73, *A*), emerging again through the *U* shaped bar on the opposite side (Fig 73 *B*) It is essential that this pin be inserted through the upper posterior tip of the tuberosity so that the traction force to reduce the disparity of the tuber joint angle and shortening is properly applied In order to determine this exact location we have used a local anesthetic needle to guide the pin insertion Before inserting the second pin through the lower tibia, the operator first applies slow, forceful traction on the os calcis by pulling on the U shaped bar This is done mainly to prevent skin tension between the os calcis and tibial pins when the extension bars are activated This traction should be maintained during the insertion of the tibial pin The insertion of the pins through the lower end of the tibia is greatly facilitated by means of the hand-operated flexible shaft drill which rotates the pins slowly and allows a free hand for the operator

The second pin also $^3/_{16}$ inch in diameter and 6 inches long is now placed in the drill chuck, passed through the pin bar (*c*) *and drilled through the lower third of the tibia* (Fig 73, *C*), about five fingerbreadths from the tip of the *internal malleolus this pin bar being held parallel to the* shaft of the tibia so that the pin will pass *transversely through the shaft of the tibia and emerge on the opposite* side through the corresponding pin bar The third pin is now *inserted through the lower channel of the pin bar*, passing through the tibia to engage the bar on the opposite side The pins are then secured to the bars by means of the set screws (Fig 73, *D*)

The foot should be held in dorsiflexion during the insertion of the tibial pins to prevent equinus and undue skin *tension*

Reduction of the Shortening and Disparity of the Tuber-Joint Angle and the Widening of the Fractured Bone

The turnbuckle lateral bars with their adjusting mechanisms (*d*) are now connected with the pin bars and tightened by hand By properly adjusting screws (*e*) and (*f*) the desired tangent for traction is obtained (Fig 73, *E*)

Reduction of the shortening and disparity of the tuber-joint angle is now obtained by activating the turnbuckle By means of wrenches, the operator simultaneously turns both turnbuckles until the desired amount of extension is accomplished (Fig 73, *F*) If possible a check x ray is now obtained, and when the shortening and disparity of the essential angle have been reduced, the *widening* is then reduced by means of compression with the os calcis clamp The os calcis is compressed until the measured distance is reached, which is usually about 1½ inches, whereupon the clamp is immediately removed

If the preliminary reduction of the shortening and disparity of the essential angle was accurate, the compressed fragments will remain in place because adequate space had been prepared for them, and the splint rigidly maintains the reduction during and after the compression We have been impressed with the lack of force required to compress an os calcis fracture in this splint The laterally displaced fragments may sometimes be replaced by hand, thus preventing unnecessary damage to the contiguous soft tissues If undue force is necessary to reduce the widening, then the shortening and disparity of the essential angle has probably not been adequately reduced, because, as in all fractures, the shortening must be corrected before the lateral displacement can be reduced

After care

Final x-rays are now taken, and if further adjustments are required, which is unusual, they may be performed without disrupting the reduction already obtained Alcohol dressings are placed about the pin sites for the first twenty-four hours, after which no dressings are used Restoration of function by means of active exercises of the knee and toes

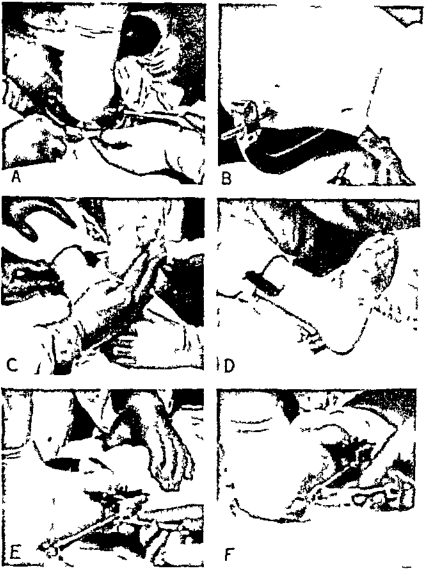


Fig 73.—*A* Pin placed in U shaped bar and then inserted through upper posterior aspect of tuberosity of os calcis *B* Pin engaging U shaped bar on opposite side Pin locked in bar by set screw *C*, Drilling pins through lower end of tibia through lateral pin bars *D* Pin bars in place pins locked in bars Ready for application of adjusting turnbuckle bars. *E* Adjusting screws for desired tangential traction *F*, Activating turnbuckles for traction.

is begun immediately, and the patient is allowed up on crutches, as he desires

Period of Immobilization

Because we desire to limit the period of immobilization to the minimum we have arbitrarily set six weeks for the cases of moderate displacement, and eight weeks for those of marked displacement This period is followed by three weeks of physiotherapy without weight bearing For the next three weeks, guarded weight bearing is permitted, the patient being discharged from treatment in three to four months Although our first nine cases have responded to this abbreviated period of immobilization, all with freely movable painless subastragaloid joints, we realize that we may be required to prolong the treatment in the severely com minuted types

End Results

The final appraisal of end results must be withheld for at least one year The possibility of the development within that time of traumatic arthritis as a result of the comparatively early full weight-bearing (four months) must be considered A careful follow up is being maintained to determine the necessity for modification of this procedure as regards the period of immobilization as well as the institution of weight bearing

REPORTS OF COMPLETED CASES

J P, aged twenty-seven years, sustained a fracture of the left os calcis by a fall of 15 feet eighteen hours before admission on March 20 1942 X rays showed moderate comminution and disparity of the tuber-joint angle Reduction was performed on March 24, 1942, by means of the modified reduction fixation splint. The splint was removed in six weeks, followed by physiotherapy for three weeks, then gradual weight-bearing Limp and limitation of dorsiflexion of the ankle persisted for six weeks Free subastragaloid joint motion was present The patient was discharged on August 15 1942, to full duty

J G, aged thirty-six years, male, suffered a compressed fracture of the right os calcis, with moderate widening and a tuber-joint angle of 5 degrees A splint was applied and the fracture was reduced on January 5, 1943 No secondary adjustments were necessary The splint was removed in six weeks The patient returned to duty in seventeen weeks with free subastragaloid motion and no pain

P G, a fifty five-year-old male, was admitted October 21, 1942 with a moderately comminuted fracture of the *right os calcis and a severely comminuted fracture of the* lower end of the left tibia and fibula with dislocation of the ankle joint, as a result of a fall from a height of 25 feet Because of his poor condition, reduction was delayed for eight days The first reduction in the splint was considered satisfactory The splint was removed in six weeks After three weeks of physiotherapy some weight-bearing was allowed (His comminuted fracture of the left tibia was also treated with a Stader splint) The patient was discharged on February 24, 1943 with free motion of the subastragaloid joint and minimal pain He *has not returned to work after four months of treatment,* chiefly due to the residual pain and stiffness of his left ankle

R S, fifty-two-year old male, was admitted January 18, 1943, with moderately comminuted and compressed fracture of the right os calcis The splint was applied and the fracture reduced on January 21 Secondary manipulation and compression was done two days later The splint was removed in six weeks The patient was discharged on April 10, 1943, with moderately free subas*tragaloid joint motion and minimal pain Slight lateral* shifting of the tibial pins and slight drainage from the os calcis pin took place during the convalescence The drainage subsided in six days

J P (see Figs 74-77), a thirty-five-year-old male was admitted November 10, 1942 with bilateral severe comminuted compressed fractures of the os calcis as a result of a fall from a height of 15 feet The fracture

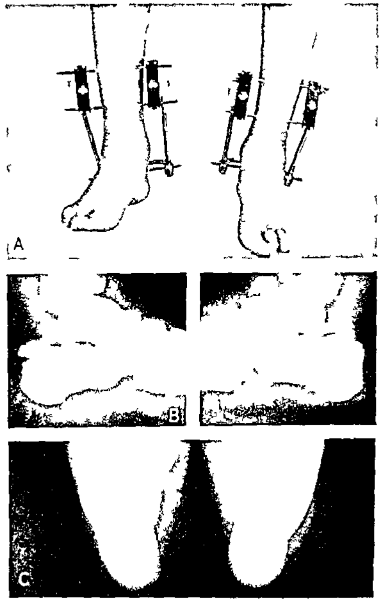


Fig 74 (J P) —*A* Bilateral severely compressed fractures of os calcis with splints in place *B* Lateral x ray views before reduction C Plantar dorsal views before reduction (See also Figs 75 76 77)

was reduced three days after the injury by means of the splint One secondary adjustment was made after five days Convalescence was smooth without pain or discomfort and free motion of the knee was begun immediately after the reduction There was no pin seepage from any of the twelve pin sites and there was no reaction about

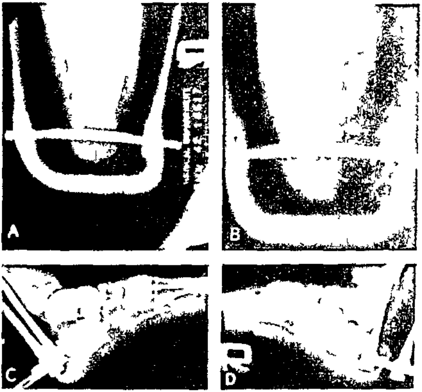


Fig 75 (Case of J P., continued).—*A*, Plantar-dorsal x ray view after reduction, right. *B* Plantar-dorsal view after reduction left *C*, *D* Lateral views after reduction (See also Figs 74 76 77)

the pins The splint was removed in seven weeks and physiotherapy begun Guarded weight bearing was permitted in nine weeks, and full weight bearing in eleven weeks The patient was discharged February 16 1943 thirteen weeks after injury There was a residual limp mild ankle pain on weight bearing, and an inability to walk on his toes He continued to return for physio-

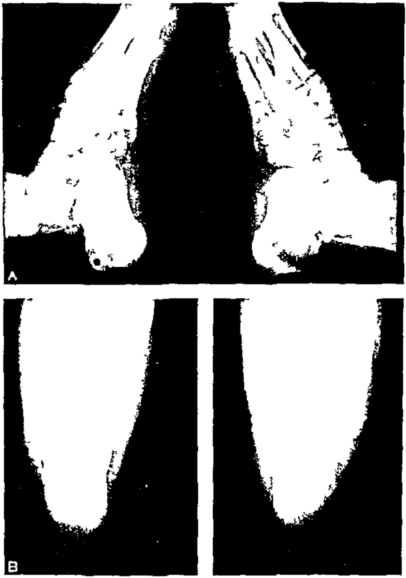


Fig 76 (Case of J P *continued*).—Final x rays plantar dorsal and lateral (See also Figs 74 75 77)

therapy, and examination on April 12 1943, revealed moderate limitation of subastragaloid joint motion and

mild crepitus on the right side The left side was normal There was no pain on walking The patient was able to walk on his toes He returned to work five months after injury

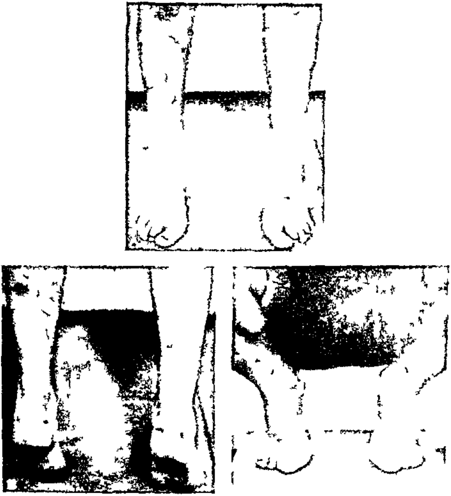


Fig 77 (Case of J P concluded).—Six weeks after removal of os calcis splints Note freedom of motion of ankles and knees, absence of atrophy of extremities and ability to stand on toe (See also Figs 74 75, 76.)

S B (see Fig 78), a man aged fifty-one years fell 8 feet and landed on his heels sustaining a moderate comminuted and compressed fracture of the right os cal

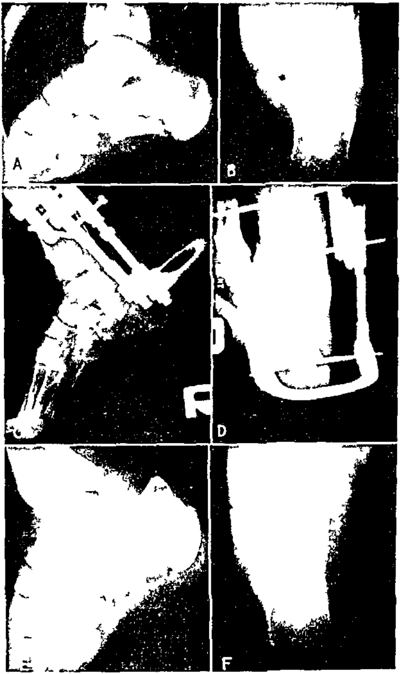


Fig 78 (S B).—*A* Preoperative lateral x ray view *B* Preoperative x ray plantar-dorsal view *C* Postoperative x ray view *D* Postoperative x ray plantar-dorsal view *E F* Final x rays after removal of splint

cis, and a Pott's fracture of the left ankle. He was admitted on June 4, 1942, the day of accident. Reduction was made on June 9 and the splint removed July 21. Guarded weight-bearing was begun on August 12. The patient was discharged from the hospital on August 15, 1942, with excellent subastragaloid motion and minimal symptoms on crutches. Full weight-bearing without crutches began on September 9. He returned to work as a Navy Yard employee on October 15, 1942.

M. M. (see Fig. 79), aged thirty-nine years, fell from a one-story roof and landed on his right heel, sustaining a moderate comminuted and compressed fracture of the right os calcis. He was admitted on June 8, 1942, a few hours after the injury. Reduction was done on June 16 and the splint removed July 28. Weight-bearing began August 20. The patient was discharged from the hospital on August 24 on crutches. Free subastragaloid motion was present without pain. He returned to work as a Navy Yard employee on December 7, 1942.

V. S., *aged fifty-two years, fell 8 feet and landed on his* left heel a few hours before admission on August 8, 1942. The x-ray showed a moderate comminuted and compressed fracture of the left os calcis. Reduction was done on August 18 and the splint removed on September 29. Weight-bearing began October 19. The patient was discharged from the hospital on crutches on October 20, 1942. Excellent subastragaloid joint motion was present, with minimal subjective complaints. He returned to work January 10, 1943, as a Navy Yard workman.

SUMMARY AND CONCLUSIONS

A new method of approach to the problem of the treatment of comminuted and compressed fractures of the os calcis is presented. The following advantages are noted:

1. The *reduction-fixation splint* is complete in itself and requires no additional equipment except an os calcis clamp.
2. It permits not only *reduction* of the fracture, but becomes the *splint* upon completion of the reduction.

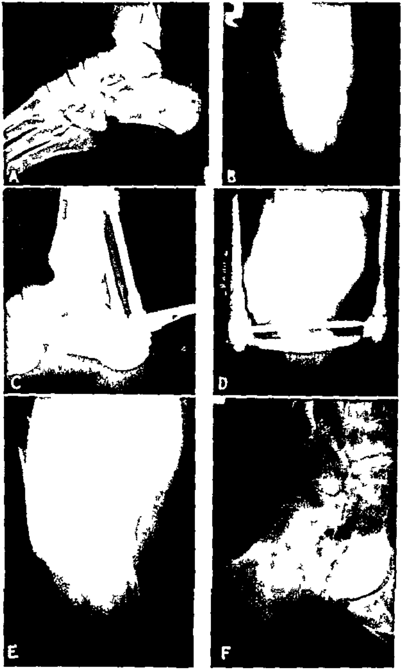


Fig 79 (M M).—*A* Preoperative x ray lateral view *B* Preoperative x ray plantar-dorsal view *C* Postoperative x ray lateral view *D* Postoperative x ray plantar-dorsal view *F F* Final x rays after removal of splint.

3 No reduction frames or plaster of paris are required

4 The type of pin placements and rigidity of the splint allows for accurate constant controlled traction in the *desired tangent* for reduction of the disparity of the tuber joint angle as well as the shortening

5 The constantly controlled traction permits overextension to produce sufficient space into which the laterally displaced fragments may be easily replaced *often by hand* or compressed by means of the os calcis clamp

6 The turnbuckles permit controlled tangential traction in either *valgus* or *varus* thus allowing maintenance of the normal varus position of the os calcis during the period of fixation as well as permitting exaggeration of either valgus or varus during the reduction

7 *The integrity of the subastragaloid joint space is constantly maintained* throughout the period of healing thereby assuring better joint motion and consequently less pain or development of post traumatic joint changes

8 The rigid fixation *promotes earlier union*

9 Secondary adjustments may be made at any time *without sacrificing the reduction already obtained*

10 Active motion of the knee and toes and ambulatory activity on crutches promotes better circulation and permits transportation of the patient without assistance

11 The constant rigid fixation of the fracture without the use of plaster or pressure pads insures a smooth uneventful convalescence *without pain discomfort or complications due to the use of plaster*

12 *The actual application of the splint is remarkably simple* and whereas a thorough knowledge of the general principles of the treatment of the difficult os calcis fracture is essential in any method of treatment, the simplicity of *the application of this method of approach makes it more* generally useful to the average traumatic surgeon without unnecessary danger to the patient.

13 This new method of approach to the problems offered by *fractures of the os calcis is based on sound anatomical* and physiological principles and accurately satisfies the fundamental requirements of fracture treatment.

SECTION V

COMPLICATIONS IN FRACTURES

CHAPTER XVI

COMPOUND FRACTURES

OUTLINE OF PROBLEM

FACTORS INFLUENCING TREATMENT

Compound Fractures

Shock

Pain Muscle Spasm Hemorrhage Loss of Fluids Depression of Vital Centers

Fractures Alone

Associated with Other Injuries

Burns Wounds (penetrating lacerated, crushing), Blast Injuries, Intracranial Injuries

Direct Violence Indirect Violence Gunshot

Single Multiple

Infected Noninfected

Bone infection — Wound infection

Involvement of Tendons, Blood Vessels, Nerves

Lacerated tendons
Tenosynovitis

Gangrene
Gas bacillus infection

Incomplete severance
Complete severance

OUTLINE OF THE TREATMENT OF COMPOUND FRACTURES

A Primary Considerations—Treatment of Shock
  1 Immediate control of major hemorrhage
  2 Immediate application of warmth to the body
  3 Immediate rigid immobilization of the fracture
  4 *Immediate injection of plasma*
  5 Immediate control of pain by adequate doses of morphine
B Secondary Considerations
  1 Treatment of associated injuries
  2 Treatment of the wound—*importance of local anesthesia*
    a Before six to eight hours
      (1) Meticulous wound excision
        Skin
        Muscles
        Tendons
        Nerves
        Blood vessels
        Bone
        Bullets and shell fragments
      (2) Reduction of the fracture
      (3) Sulfonamides in the wound (efficacy debatable)
      (4) Closure of the wound
    b After eight to ten hours—wound potentially infected
      (1) *Wound cleansing and essential debridement*
        Skin
        Muscles
        Tendons
        Nerves
        Blood vessels
        Bone
        Bullets and shell fragments
      (2) Reduction of fracture
      (3) Sulfonamides in wound
      (4) *Open wound treatment*

C After-care
  1 General
    a Adequate supportive treatment
    b Sulfonamides orally or intravenously
    c Antitetanic antitoxin tetanus toxoid
    d Gas bacillus antitoxin
  2 Treatment of the fractured extremity
    a Compression bandage to leg
    b Elevation of the leg
    c When to begin activity
    d Prophylactic use of x ray therapy gas infection wound infection
    e Care of wound

THE IMPORTANCE OF EXTERNAL SKELETAL FIXATION IN THE TREATMENT OF COMPOUND FRACTURES

The pain and muscle spasm incident to all compound fractures is probably the most important single factor in shock Unless the fracture is rigidly immobilized large amounts of morphine may be required to relieve the pain With absolute rigid fixation pain and muscle spasm quickly disappear Following this rigid fixation the remaining shock is more amenable to treatment by plasma and other medications

Because the splint may be routinely applied under local anesthesia the operation does not materially add to the shock especially when 0 5 per cent procaine is used In the case of fractures of the tibia relatively small amounts of the novocain solution need be used sometimes as little as 30 cc A splint set should be sterilized and kept available for emergencies It is as important as having plasma on hand

Unless associated injuries contraindicate it the wound treatment is begun immediately after the application of the splint and while the plasma is being given Debridement and wound care may however be delayed should the patient s condition warrant it or where many casualties must be treated in a relatively short time Preliminary fixation with the splint permits accurate meticulous débridement under the most ideal conditions for surgical treatment of the wound—that of rigid control of the fragments throughout the operation (Fig 80) Retraction of the tissues is limited

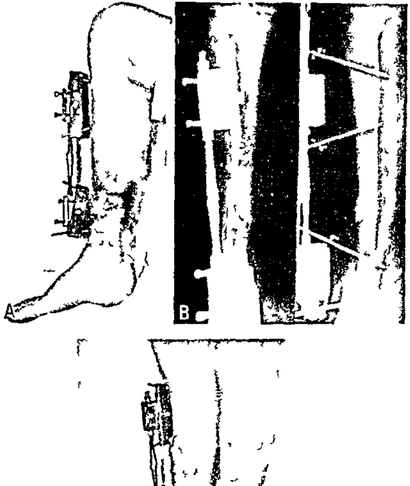


Fig 80.—C K., a twenty five year-old male had a compound fracture of the tibia at the junction of the middle and lower third The Stader splint was applied one day after the accident Weight bearing was permitted from the first postoperative day

A The splint applied *B* X ray film with splint in place *C* Photograph taken after fourteen weeks immobilization showing lack of muscle atrophy and pin seepage

to a minimum and proper exposure of the entire wound facilitated Additional trauma to the tissues is thus avoided Because control of the fragments with the splint is secured outside of the wound, the use of bone-holding forceps or bone retractors is eliminated The operation need not be

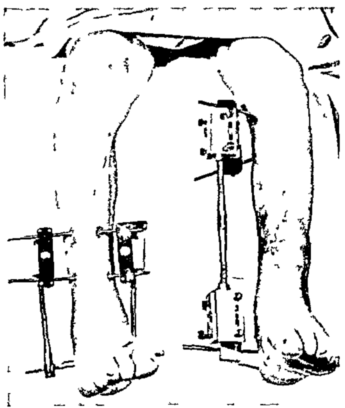


Fig 81.—Compound fracture of left tibia and ankle joint, associated with fracture of right os calcis and skull injury Immediate immobilization with splints allowed freedom of activity and proper care of intracranial injury

hurried under these conditions The amount of plasma usually necessary in the control of shock is greatly diminished

When associated injuries are present, treatment of the fracture by external skeletal fixation allows the patient to move about the bed at will (Fig 81) Skull injuries seldom

require special restraining devices or medications. Spinal punctures may be performed without difficulty and with minimal danger to the patient. Genito-urinary operations may be performed unhindered by plaster of paris or traction encumbrances. Necessary examinations and other surgical procedures do not have to be delayed or omitted because of the fracture. Burns can be treated by any desired method. In fact, the patient may be treated as if he had no fracture if other important injuries are present, unless of course there are existing complications of the fracture itself. The entire problem of the individual fracture case is greatly simplified because: (1) there is *no plaster-of-paris* cast; (2) there are no traction devices or weights and pulleys; (3) the patient is not necessarily confined to his bed and may be moved about at will or transferred to any desired place for other examinations and treatment; (4) as soon as the fracture is immobilized in the splint, *the fracture problem itself may be temporarily put aside in favor of any* other existing disability or injury.

In fourteen cases of compound fractures of the tibia treated with the splint, there were no infections, in spite of the fact that six of these were treated after ten hours, and three were treated after twenty hours (Fig. 82). It is believed that *rigid fixation was the most important factor in* the production of these results. It is certain that the normal physiology of bone and soft tissue relationship was better established by this means. Proper absorption and drainage of the wound site is influenced by bone stability and active motion of the adjacent joints. The soft tissues may be supported *if necessary. Whether or not infection takes place in* a compound fracture after all must depend upon many other factors, e.g., the type and number of infecting organisms and the vital resistance of the patient, both locally and generally.

Constant movement of the fracture site produces added injury to the adjacent tissues and therefore interferes with the resistance against potential infection. Motion of the fracture site also produces edema and swelling which dilutes the normal protective juices of the tissues as well as inter-

feres with the proper drainage and thus produces a stagnation of fluids in which bacteria may readily multiply We are impressed with the fact that the swelling and edema of compound fractures is minimized and subsides early under the influence of the rigid fixation and early joint motion permitted by this method

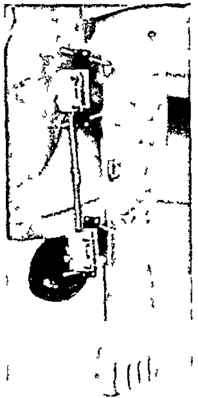


Fig 82.—Compound fracture of left tibia treated after twenty hours Wound healed without infection Patient ambulatory in fourteen days. Note lack of swelling of ankle and foot.

OUTLINE OF THE DETAILS OF TREATMENT OF COMPOUND FRACTURES

1 **Immediate Application of the Splint under Local Anesthesia**

This is performed as an adjunct to the treatment of shock and is often completed before the plasma injection

has been completed The extremity is prepared as for any operation, and a sterile gauze dressing is placed over the wound *At least 2 pints of plasma are given routinely in all cases of major compound fractures* The pins are inserted and the connecting bar assembly is applied The extremity is lined up but no attempt is made to reduce the fracture at this time if the patient's condition does not permit it

2 Treatment of Associated Injuries, If Present

The treatment of shock is continued as other injuries are taken care of

3 Reduction of the Fracture

In most cases, the fracture is reduced immediately after the application of the splint It is performed while the position of the fragments is under direct observation permitting anatomic reposition

4 Wound Excision or Debridement

a Treatment before Eight Hours

The entire wound including skin subcutaneous tissues and all devitalized muscles is meticulously excised The wound is most often extended so as to obtain a wide exposure especially in compound fractures due to indirect violence *where the skin wound may be present at a distance from* the actual fracture Thorough lavage of the wound with copious amounts of normal saline or distilled water is carried out during the operation to mechanically clean the *wound of debris Muscle that does not bleed when cut is not* viable and should be removed All devitalized and contaminated tissues are removed

Tendons —Severed tendons are not sutured The proximal end is secured to the overlying tissue with a single cotton or silk suture to prevent its retraction A wire loop may be used to secure the proximal end, the wire being passed out through the skin above the wound Frayed and contaminated ends are debrided in the same manner as are all other tissues

Nerves —Important nerves are always sutured with fine

silk or cotton Immediate repair of the nerve is advisable Satisfactory results in such attempts have been obtained in spite of a low grade wound infection Even if failure results, primary suturing will prevent retraction of the nerve end and facilitate secondary operation

Blood Vessels—Clamping should be sufficient to stop bleeding from smaller vessels without applying ligatures If the blood supply of the extremity is completely destroyed amputation should be performed

Muscles—Muscles should not be sutured The devitalized muscle fibers engulfed within the sutures act as a culture media for bacteria, especially the gas forming variety Damaged and devitalized muscle predisposes to gas infection

Buried Sutures—Bohler's warning "suture the skin and only the skin" should be heeded Nothing will do more harm to an otherwise good débridement than the useless burying of catgut or other foreign bodies Even joint ligaments and capsules do not require suturing Buried sutures predispose to infection

Bone—Fragments devoid of periosteal attachment are removed, if contaminated, unless they are very large The extensive or unnecessary removal of bone fragments results in delayed and nonunion However, when in doubt, it is better to remove the fragment than to subject the patient to the danger of osteomyelitis

Bullets and Shell Fragments, and Other Foreign Bodies—Bullets, shell fragments, and other foreign bodies are always removed if accessible, but no extensive search is made for them If an inaccessible shell fragment is present, the wound should be left open and lightly packed with vaseline strips

Implantation of Sulfonamides in the Wound—Implantation of 4 gm of sterile powdered sulfanilamide evenly distributed in the wound may be done if desirable

Wound Closure—In most cases treated within eight hours of the injury, the wound may be closed primarily Tension incisions are routinely made especially on the tibia in order to close the wound The skin over the wound must never be under tension because the edges may slough and

infection result The skin over the wound protects the underlying tissues from becoming secondarily infected *In military surgery however most compound fractures should not be closed*

Application of Pressure Bandage —The general belief is that support of soft tissue by a firm bandage or cast is essential in compound fractures In the small group of cases that came under our observation no soft tissue support was applied Soft tissue swelling usually subsided in a few days The controlling factor is the rigid uninterrupted skeletal fixation

b Treatment after Eight to Ten Hours

The treatment of compound fractures received late demands considerable experience and judgment as to when or when not to operate The general condition of the patient should be the primary consideration A rising pulse rate pain in and about the wounds marked tenderness a sensation of tension increasing edema thin foul sanguineous discharge (anaerobe) and a spreading mottled bronzing discoloration of the skin in a patient who is pale and apathetic and who does not respond to treatment are indications of deep and spreading infection

With *fixation well established* free drainage should be instituted foreign bodies should be removed and obviously devitalized tissue particularly muscle must be excised without damage to the lining wall of the wound This is not wound *excision or débridement* which should never be attempted after twelve to twenty hours Measures to control hemorrhage are instituted sulfonamide is implanted and the wound is packed lightly with vaseline strips avoiding the use of drainage tubes In cases of suspected gas gangrene x ray therapy alone may be sufficient and surgery may not be indicated Careful early treatment will avoid a high rate of amputation *Polyvalent sera should be used in all suspected cases* In addition to the local implantation of sulfonamide its oral or parenteral administration is of importance to maintain a blood level of 6 to 8 mg per 100 cc until danger of infection has completely subsided

5. After-care

a GENERAL SUPPORTIVE CARE

The postoperative care of compound fractures is very important and is dependent upon the general condition of the patient and the extent of the injury Necessary precautions against delayed shock must be taken (see chapter on Shock) Whenever possible, blood transfusions should be given in cases of hemorrhage Patients treated in the splint are usually reasonably comfortable and require little morphine If morphine is required after 48 hours, one should suspect the development of complications, such as infection, phlebitis, or improper application of the splint with failure to obtain rigid immobilization

b PROPHYLAXIS AGAINST TETANUS AND GAS INFECTION

It cannot be too often repeated that the best prophylaxis against tetanus and gas infection is proper meticulous treatment of the wound, especially the removal of all foreign bodies and the excision of all devitalized muscle

All military personnel are protected against *tetanus* by the injection of toxoid In these cases, it is only necessary to administer a "booster" injection of 1 cc of the toxoid In patients who have not been immunized with toxoid, tetanus antitoxin is given

Treatment by external skeletal fixation permits direct inspection of the wound and the entire extremity to detect the earliest signs of *gas infection* Inordinate pain is a constant finding in the deep phlegmonous type, whereas crepitation is an early finding in the superficial type The advisability of routine administration of polyvalent gas bacillus serum in compound fractures is questioned It often produces considerable local and systemic reactions, and therefore should be given only in selected cases Where proper x-ray facilities are at hand, x ray therapy is recommended as a prophylaxis against gas infection The desired quality of irradiation is that generated at 200 kv and filtered with 0 5 mm of copper and 1 mm of aluminum This should be administered twice daily for two or three

days giving 100 r at each treatment. The portals of irradiation should extend well beyond the obvious wound. A regimen such as this permits the continuation of irradiation therapy should a gas bacillus infection develop.

c. CHEMOTHERAPY IN THE TREATMENT OF COMPOUND FRACTURES

The routine administration of sulfonamides either by mouth or by vein to maintain a blood level of 6 to 8 mg. per 100 cc., in all patients with compound fractures, is advisable.

Sulfanilamide is the drug of choice for *local implantation.* Four to 5 gm. are implanted in the wound and well distributed over the wound surface. Sulfanilamide implantation should be followed with *oral administration* of sodium sulfadiazine or sulfanilamide. The former is preferable because it is less toxic.

Two grams of sodium sulfadiazine should be taken at once orally. Following this, 1 gm. is given every six hours to maintain a proper blood level (6 to 8 mg. per 100 cc.). Treatment is continued for seven days at the end of which time, if the wound is clean and there is absence of fever, therapy is discontinued.

5. After-care

a GENERAL SUPPORTIVE CARE

The postoperative care of compound fractures is very important and is dependent upon the general condition of the patient and the extent of the injury Necessary precautions against delayed shock must be taken (see chapter on Shock) Whenever possible, blood transfusions should be given in cases of hemorrhage Patients treated in the splint are usually reasonably comfortable and require little morphine If morphine is required after 48 hours, one should suspect the development of complications, such as infection, phlebitis, or improper application of the splint with failure to obtain rigid immobilization

b PROPHYLAXIS AGAINST TETANUS AND GAS INFECTION

It cannot be too often repeated that the best prophylaxis against tetanus and gas infection is proper meticulous treatment of the wound, especially the removal of all foreign bodies and the excision of all devitalized muscle

All military personnel are protected against *tetanus* by the injection of toxoid In these cases, it is only necessary to administer a "booster" injection of 1 cc of the toxoid In patients who have not been immunized with toxoid, tetanus antitoxin is given

Treatment by external skeletal fixation permits direct inspection of the wound and the entire extremity to detect the earliest signs of *gas infection* Inordinate pain is a constant finding in the deep phlegmonous type, whereas crepitation is an early finding in the superficial type The advisability of routine administration of polyvalent gas bacillus serum in compound fractures is questioned It often produces considerable local and systemic reactions, and therefore should be given only in selected cases Where proper x-ray facilities are at hand, x-ray therapy is recommended as a prophylaxis against gas infection The desired quality of irradiation is that generated at 200 kv and filtered with 0 5 mm of copper and 1 mm of aluminum This should be administered twice daily for two or three

5 After care

a GENERAL SUPPORTIVE CARE

The postoperative care of compound fractures is very important and is dependent upon the general condition of the patient and the extent of the injury Necessary precautions against delayed shock must be taken (see chapter on Shock) Whenever possible, blood transfusions should be given in cases of hemorrhage Patients treated in the splint are usually reasonably comfortable and require little morphine If morphine is required after 48 hours, one should suspect the development of complications, such as infection, phlebitis, or improper application of the splint with failure to obtain rigid immobilization

b PROPHYLAXIS AGAINST TETANUS AND GAS INFECTION

It cannot be too often repeated that the best prophylaxis against tetanus and gas infection is proper meticulous treatment of the wound, especially the removal of all foreign bodies and the excision of all devitalized muscle

All military personnel are protected against *tetanus* by the injection of toxoid In these cases, it is only necessary to administer a "booster" injection of 1 cc of the toxoid In patients who have not been immunized with toxoid, tetanus antitoxin is given

Treatment by external skeletal fixation permits direct inspection of the wound and the entire extremity to detect the earliest signs of *gas infection* Inordinate pain is a constant finding in the deep phlegmonous type, whereas crepitation is an early finding in the superficial type The advisability of routine administration of polyvalent gas bacillus serum in compound fractures is questioned It often produces considerable local and systemic reactions, and therefore should be given only in selected cases Where proper x-ray facilities are at hand, x-ray therapy is recommended as a prophylaxis against gas infection The desired quality of irradiation is that generated at 200 kv and filtered with 0 5 mm of copper and 1 mm of aluminum This should be administered twice daily for two or three

6 Treatment of the Fractured Extremity

All compound fractures should be kept at rest in elevation for the first forty-eight hours, or longer if necessary The position of the part should be the most comfortable for the patient, the adjacent joints usually flexed Active motion is allowed and encouraged as soon as the primary reaction to the trauma has subsided Massage of the part is not recommended The wound is not dressed for at least five to seven days, unless signs of infection are present In the wounds treated by the "open method," the top gauze dressing may be removed in ten days or more, but the vaseline pack is not disturbed for at least three to five weeks After the first pack has been removed, it may be desirable to leave the wound entirely open and allow the wound to granulate from all sides Such wounds often heal in a relatively short time The daily or frequent spraying of the wound with sulfonamides should be discouraged The patient is allowed up and out of bed on crutches as soon as his temperature is normal and his general condition permits If the soft tissue damage has not been extensive and infection has not occurred, the patient is usually up and about in five to seven days Weight-bearing, however, is usually not recommended for two to three weeks

CHAPTER XVII

COMPOUND FRACTURES WITH OSTEOMYELITIS

The principles of treatment, as laid down by Orr, govern the modern accepted treatment of compound fractures with osteomyelitis Immobilization of the fracture and prolonged "*intelligent neglect*" *of the wound is the basis of this treatment* Bohler stresses the importance of the "uninterrupted immobilization" of the Orr management, while others believe that the "bacteriophage" qualities of the wound secretion play the leading role Failure of the Orr treatment usually means either failure to obtain proper immobilization (not including both the joint above and below in the cast) or the injudicious fenestration of the cast and premature redressing of the wound

Disadvantages of the Orr Method

In spite of the evident success of the Orr treatment in the majority of cases of compound fractures with osteomyelitis, *it* can nevertheless be said that it has several objectionable features

1 *Odor*—Whereas the patient himself may eventually become sufficiently immune to the objectionable odor of the cast, those who are forced by circumstance to associate with him are not always so fortunate This is particularly true on board ship where many are confined in relatively small, often closed, spaces

2 *Prolonged Immobilization*—Prolonged immobilization of the fractured extremity including the joint above and the joint below the fracture has many serious objections

a It produces extensive demineralization of the bones, which is not conducive to the healing of bone The blood flow to the extremity is greatly decreased and the normal metabolism of the bone is impaired The calcium content of the bone is absorbed *from the* matrix The greatest impetus to normal bone

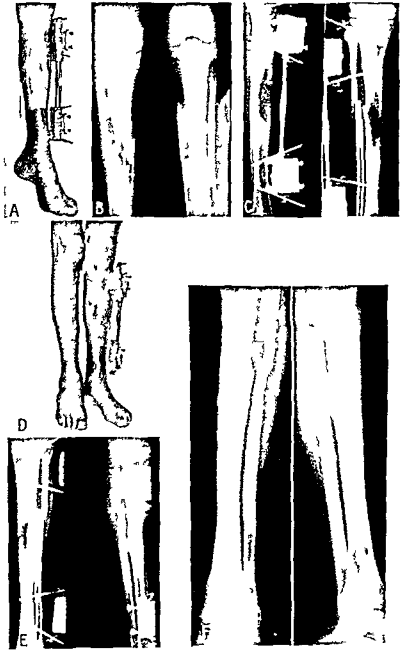


Fig 83

growth is functional activity of the part, and no amount of calcium therapy will stop or decrease the progressive demineralization due to prolonged immobilization The calcium content of the blood in these cases is normal but the injured extremity does not get enough of it

b *Prolonged immobilization of the entire extremity not* only retards healing of the bone but also prevents or delays the necessary reconstructive surgery after the fracture has healed

c It invariably causes marked stiffness of the joints which often especially in the aged, persists for months after the cast has been removed This factor also delays or prevents the reconstructive surgery which is necessary in a large percentage of these cases

3 *Complications Due to the Cast Itself*—Plaster casts often cause serious complications especially in the military services when patients must be evacuated at sea or transported over long distances soon after the operation When wet, the cast not only acts as an anchor, but it softens and loses its function as an immobilization agent Some military surgeons advise splitting the cast immediately after the operation if the patient is to be transported over long distances to avoid the complications of swelling under the cast and to facilitate its quick removal when it becomes necessary to abandon ship

Advantages of the External Skeletal Fixation Splint in Treatment of Compound Fractures with Osteomyelitis

In no type of fracture is rigid fixation so important as in compound infected fractures The constant maintenance of

---

Fig 83 (C T)—Compound fracture of midshaft of tibia of one month's duration Plating unsuccessful *A*, Immediately after application of Stader reduction splint *B* Preoperative x ray film *C* Postoperative x ray film *D* After four months immobilization in the splint. Note lack of swelling atrophy and pin seepage Guarded to full weight bearing was allowed *E* X ray film four months after injury *showing bony union and lack of bone reaction about the pins* *F* Final x rays six months after injury

absolute rigid fixation of the bone is the basis of the success in treatment Support and rest of the soft parts is necessary only until the reactive inflammation has subsided External skeletal fixation is advantageous in the management of these cases for the following reasons

1 It provides absolute rigid fixation of the fracture *without fixing the adjacent joints* Normal physiology of the fractured limb is thereby not interfered with throughout the healing process Adequate blood flow to the extremity is maintained and the normal metabolic processes of the bone assured The bone loses little if any of its mineral content Progressive demineralization of the bones is minimal or entirely absent (Fig 83)

2 Active motion prevents stiffness of the adjacent joints and the disability incident thereto

3 If reconstructive surgery is indicated at a later date, the surgeon will have good mineralized bone and healthy soft structures to work with He will not need to delay surgery for preparation by physiotherapy

4 The objections of plaster are eliminated Immersion in sea water is not harmful but is actually beneficial, as was proved in the evacuation of the wounded at Dunkirk Many believed that wounds that were in sea water for any length of time were actually benefited as the incidence of infection was less

5 The wound is packed lightly with strips of sterile vaseline gauze and left undisturbed unless important indications justify interference

6 The fixation of the fracture with the splint gives sufficient rigidity to permit the patient, in case of an emergency, such as abandoning ship to become ambulatory with little or no assistance The hazards of transportation are minimized

The illustrated case (Fig 83) is an example of the distinct advantages stated above

CHAPTER XVIII

OLD UNUNITED FRACTURES

Most cases of ununited fractures are complicated by stiffness of joints, muscle atrophy, and demineralization of the bones The disability is often disproportionate to the severity of the fracture and is mainly due to prolonged and extensive immobilization in plaster (Fig 36) From the functional standpoint, therefore, the treatment of nonunion is very difficult Operation must often be delayed for weeks or months to improve the condition of the soft tissues as well as joint function Such delays produce economic hardship on the patient in civil life and in the military services prevents an early restoration to duty

Controlled external fixation, in most instances, permits immediate operation for the treatment of old ununited fractures, provided the mineral content of the bone is sufficient to allow firm anchorage of the pins Where demineralization of the bone is excessive, it is advisable to avoid the bone extremities for the pin insertions and select the firmer cancellous bone of the shaft for a firmer anchorage Where firm pin anchorage can not be obtained, treatment by external fixation is inadvisable

Various operative procedures have been recommended in the treatment of old ununited fractures Most of these are concerned with the introduction of a bone graft after freshening the fracture site Internal fixation by plates alone or an osteoperiosteal graft under a plate (McBride) have been recommended The question as to the importance of controlled impaction of the bone ends as a factor in producing good results is debatable Evaluation of results obtained by external fixation must await further critical study and analysis of cases It appears distinctly advantageous to be able to keep the well freshened bone ends firmly apposed

Fig 84

throughout the healing process while at the same time allowing activity of the joints

Nonunion of fractures is often due to infection The drainage may have subsided and the wound may have healed but usually the case becomes one of chronic recurring osteomyelitis complicated by nonunion It has always been taken for granted that bone grafting or similar operations for nonunion was contraindicated in the presence of a chronic osteomyelitic process Recent successful use of an osteoperiosteal graft under a plate (McBride) in these cases suggested the importance of rigid immobilization as a factor in the success of the operation Controlled skeletal fixation was used to obtain this rigid fixation and also to firmly impact the graft into the bone ends Full thickness bone grafts whose ends were cut in the shape of a V and beveled so as not to slip out of place during impaction were inserted directly into the infected fracture area after excision of the bone ends No internal fixation of the graft was used and the graft was kept firmly in place by impaction alone (Fig 84) The operative incision was made directly through the infected area and the wound left open Two cases so treated have healed in spite of the fact that in one case about 4 inches of the graft was exposed in the wound and there was considerable drainage for several weeks after the operation (Fig 85) These cases are presented for their interest value as well as to emphasize the importance of rigid fixation in the healing of infected bones This fixation with active use of the extremity and without the implantation of any

---

Fig 84—H G a forty five year-old male had an old compound fracture of the upper third of the left tibia of two years duration He was treated at first by bone plate which sequestrated with loss of 2 inches of tibia Recently he suffered a fracture of the fibula with an acute flare-up of osteomyelitis and copious drainage The Stader splint was applied May 8 1942 and a 5-inch full thickness tibial graft was inserted without any internal fixation A remarkable convalescence ensued with free motion of the leg without pain or febrile reaction and with subsidence of drainage and weight bearing in three weeks Firm union resulted in five months Wound healed

A Stader reduction splint applied *B* Preoperative x ray film *C* Postoperative x ray view *D* and *E* Final x rays anteroposterior and lateral five months after operation showing firm union of graft.

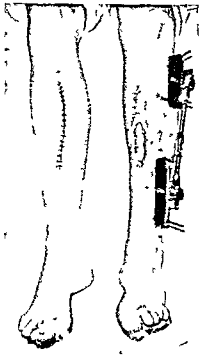


Fig 85.—Old ununited fracture of left tibia with osteomyelitis and loss of bone, of five years' duration Three previous operations Large bone graft inserted through infected area Four inches of graft remained exposed Marked drainage for three weeks Graft kept firmly embedded by repeated impaction by means of the turnbuckle Note lack of swelling and good condition of soft tissues Active exercises of knee and ankle throughout healing process

foreign material, is feasible and gives promise of being a satisfactory method The constant controlled impaction of the graft seemed to have been a valuable factor in the success of these cases (For further consideration of the treatment of old ununited fractures, see chapter on Bone Grafts)

CHAPTER XIX

OLD FRACTURES WITH MALUNION

The incidence of malunion of fractures increases in time of war because of the type of fractures and difficulty to apply and sustain traction when treating a large number of casualties Oblique and comminuted fractures usually require sustained traction to prevent overriding and deformity It is of interest, however, to note that occasionally in the more severely comminuted gunshot fractures treated by simple plaster cast immobilization very little overriding resulted This is probably due to the concomitant muscle injury

Malunion is usually not associated with the extensive decalcification atrophy and stiffness of joints which characterizes nonunion Instead there are all types of impairment of function because of the disturbances in bone alignment overriding synostosis and changes in muscle *pull and joint mechanics Secondary nerve involvement is* not uncommon

Value of the External Skeletal Fixation Splint in Corrective Osteotomies and Fragment Realignment

Corrective osteotomies and fragment realignment with or without bone lengthening is the most common operative procedure in the treatment of old fractures with malunion The mechanical features of controlled external skeletal fixation lend themselves to the successful management of this type of reconstructive surgery for the following reasons

1 Because of the absence of extensive demineralization the pins can usually be well seated to permit good control of the fragments
2 By means of the adjusting screws the osteotomized fragments may be accurately controlled under direct vision regardless of the abnormal muscle pull Me-

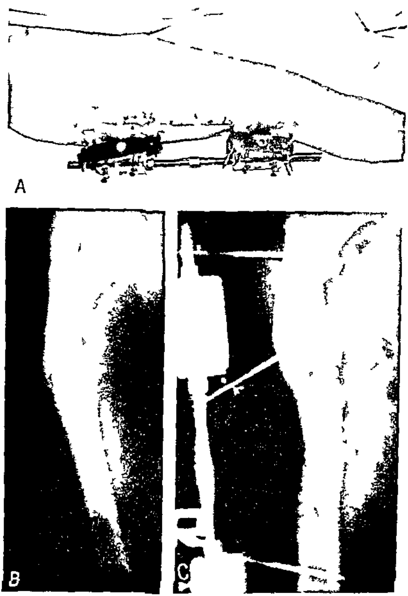


Fig 86 (N M) —Malunited fracture of shaft of right femur of seventeen years duration with marked varus deformity and shortening of 2¼ inches The Stader reduction splint was applied and a long oblique osteotomy of the midshaft of the femur was performed Partial correction of the varus deformity was obtained at the t me of

chanical adjustment by means of screws is positive and forceful and should be performed slowly

3 By activating the turnbuckle the bone ends may be gradually distracted Distraction may be performed over a period of weeks, if advisable, to obtain proper bone length This gradual controlled extension permits bone lengthening with minimal damage to the soft parts, especially blood vessels and nerves (Fig 86).

Application of the Splint in Special Malunited Fractures

The external skeletal fixation splint is of special value in corrective osteotomies for the treatment of malunited fractures of the *forearm* because the deformities are so complex and impairment of function so great (Fig 87) Firm fixation of the osteotomized bones, with free joint motion during the healing period, favors earlier return of function In some cases it may be desirable to supplement the corrective osteotomy with some type of bone graft It is necessary in all cases of corrective osteotomies of the forearm to use a regular radius splint, and if both bones are involved, to use a splint on each bone The splints are applied as described in the chapter on fractures of the forearm If only the radius has been osteotomized (Fig 88), especially in its middle third, it is advisable to support the forearm with a plaster splint for a few weeks The plaster splint may be removed daily to permit guarded motion of all joints Where both bones have been osteotomized and a splint applied to both of them, the patient usually has about 25 to 50 per cent range of pronation and supination which does not tend to place an abnormal strain on the radius and therefore does not require a protective plaster splint.

Corrective osteotomies of the *lower leg* should usually include an osteotomy of the fibula

---

the operation. By weekly adjustments for further varus correction and femoral lengthening were performed at the bedside In the first two weeks 1¼ inches of lengthening was obtained Final correction 2 inches of leg length was obtained

A Stader reduction splint applied. *B*, Preoperative x ray film *C* X ray taken two weeks postoperatively

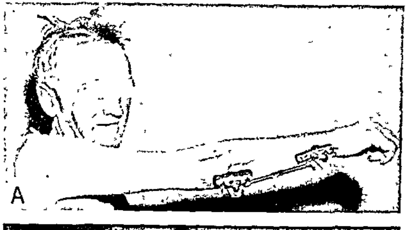


Fig. 87 (W. M.).—Malunited fracture of upper third of right ulna and anterior dislocation of head of radius in a forty-six-year-old male. A Stader splint was applied, the head of the radius was removed, the ulna osteotomized at the fracture site, and the fracture reduced under direct vision by means of the splint. Final result: firm union and good function.

A, Stader reduction splint applied. *B*, Preoperative x-ray film. *C*, Postoperative x-ray view.

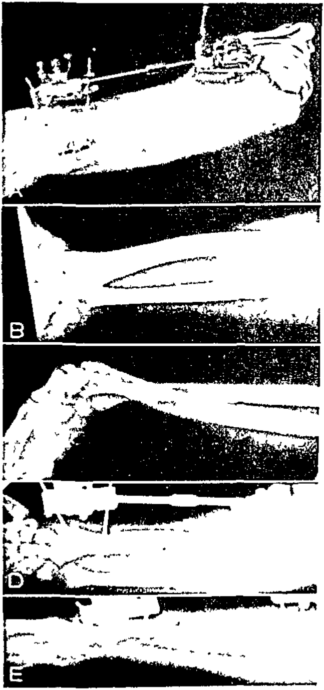


Fig. 88.—*A*, Osteotomy of radius for chronic radio-ulnar dislocation. Note deformity and length of radius. *B*, and *C*, Preoperative x-rays. *D*, and *E*, Postoperative x-rays.

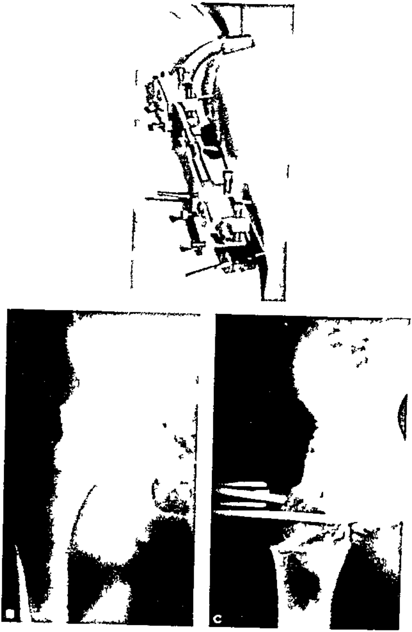


Fig 89

Osteotomy of the *os calcis*, to correct a flattened tuberosity and relaxed heel cord, may be performed with the aid of the os calcis splint The os calcis is osteotomized through a lateral approach beginning just posterior to the posterior articulation and directing the osteotomy forward at an angle of about 15 degrees By means of the turnbuckles the tuberosity is brought down and the heel cord moderately stretched Cancellous bone chips from the upper tibia may be used to fill in the opening wedge of the osteotomy

Osteotomy of the *femur* may be performed in the shaft or in the subtrochanteric region In the latter case the right angled pin bar is used for the trochanter (Figs 51 55) as described under subtrochanteric fractures A supportive plaster cast is not required because the fixation is sufficiently rigid with the splint alone (Fig 89)

The regular femoral unit should be used for osteotomies of the shaft of the femur, and care should be exercised in the proper insertion of the pins, especially when femoral lengthening is desired The strains and stresses placed on the splint are at their maximum in femoral lengthening operations (Fig 86)

In malunited fractures *with nerve involvement* it may be advisable to expose the nerve first to determine the necessary amount of neurosurgery required Malunion, as well as other fracture complications sustained in war zones, are often associated with peripheral nerve injury This adds considerably to the difficulty in reconstructive surgery Whether the malunion should be corrected before the secondary nerve repair, or performed simultaneously, is a problem to be considered in each individual case In cases where there is considerable loss of nerve tissue in an important nerve, and the usual methods fail, one may consider the method of bone shortening controlled by external skeletal fixation

---

Fig 89—*A*, High subtrochanteric osteotomy of the femur for chronic arthritis of the hip joint (see diagrammatic drawing Fig 55) *B* Preoperative x ray, showing marked osteoarthritic changes Flexion deformity and limitation of abduction *C*, Postoperative x ray Note upper pins securely fixed in the trochanter

SECTION VI

ARTHRODESIS OF JOINTS

CHAPTER XX

ARTHRODESIS OF JOINTS

The success of an arthrodesis often depends upon mechanical factors After adequate joint resection it is necessary to hold the bone ends firmly apposed in proper position until union has been established Failure of or delay in fusion of the joint may be due to insufficient or inconstant apposition of the bone ends Maintenance of proper position after the wound has been closed and during the application of the cast is often difficult Controlled external skeletal fixation is indicated in those cases in which the aid of the mechanical advantages of the splint are desired It is applicable to the arthrodesis of most joints

The *advantages* of controlled external skeletal fixation may be enumerated as follows

1 Visual control of the impaction of the resected bone ends during the operation by activating the turnbuckle bar
2 Rigid immobilization during the closure of the wound as well as after the operation
3 Added plaster cast immobilization is usually not necessary but may be used if indicated
4 Freedom of motion of adjacent joints
5 Promotes better healing and earlier arthrodesis

Arthrodesis of the Knee Joint

The regular femoral unit is necessary for arthrodesis of the knee joint because the added strength of the splint is required to overcome the leverage of the leg on the thigh

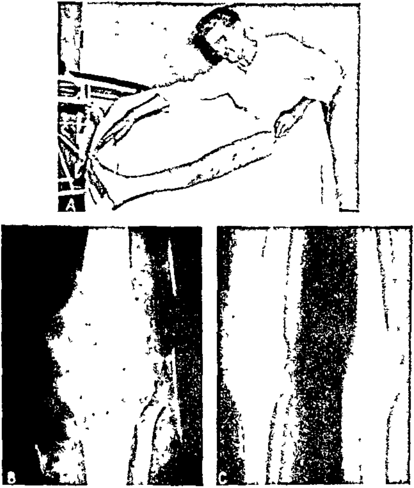


Fig 90 (M. E.) —Transfixation of knee joint in arthritis by means of the Stader reduction splint. The patient, a forty-eight-year-old male, was seen with a severe infectious arthritis of the knee joint of eleven years' duration. The splint was applied and permitted to remain for seven weeks. Firm arthrodesis resulted in eight weeks. Swelling of the ankle disappeared with active motion of the extremity in the splint.

A, The knee upon removal of the splint. *B*, Preoperative x ray film. *C*, X-ray view two months later.

The splint is applied to the lateral aspect of the thigh and leg, the upper pin unit being inserted into the lateral surface of the middle third of the femur and the lower pin into the lateral surface of the middle third of the tibia (Fig 90) A protective posterior plaster splint support is recommended because of the stresses and strains over the joint

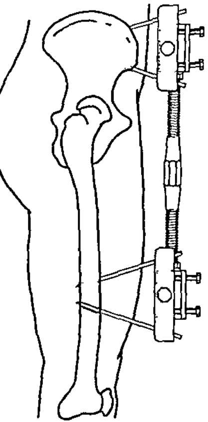


Fig 91.—Diagram of the Stader reduction splint for transfixation of the hip joint

Arthrodesis of the Hip Joint

Arthrodesis of the hip is the most difficult of all arthrodeses The plaster-of paris cast is extremely uncomfortable to the patient, increases the nursing care, and does not afford absolute immobilization of the hip Satisfactory rigid

fixation of the hip joint can be achieved by external skeletal fixation For this purpose, the joint is bridged from the iliac crest to the femur (Fig 91) One half-pin unit is applied to the ilium in such a way that the first pin enters the bone in the region of the anterior superior iliac spine and is drilled through the ilium in a posterior direction beginning near the medial surface of the ilium and emerging from it *through its lateral surface after passing through about 1½* inches of the wing The second pin after passing through the channel of the pin bar engages the crest of the ilium in its thick portion and is also drilled in a posterior direction through the wing of the ilium beginning near its medial surface and emerging laterally after passing through about an inch of the bone The converging pins of the half-pin unit if properly inserted, will firmly grip the ilium and permit mechanical bridging of the hip joint without the aid of a plaster cast The second pin unit is applied to the anterolateral surface of the mid third of the femur, the pins passing through the quadriceps When the connecting bar assembly has been attached rigid fixation of the hip is attained

This type of external skeletal transfixation of the hip may be maintained for an indefinite period of time When the pins through the ilium have been properly inserted, they will not become loose The patient may be moved about in bed, facilitating the nursing care Activity of the knee and *ankle is permitted With rigid fixation obtained there is* little postoperative pain or discomfort (Fig 92)

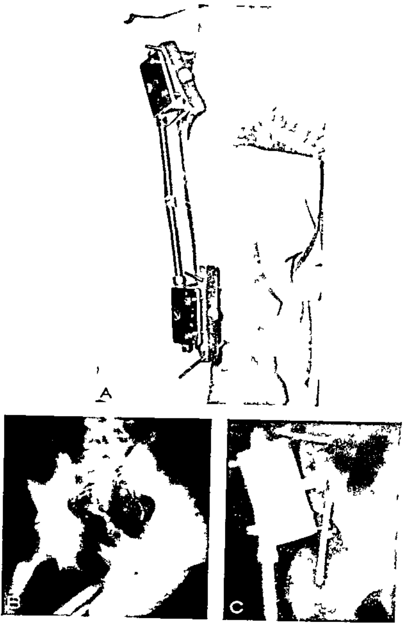


Fig 92

Fig 92.—Arthrodesis of hip joint following rigid immobilization for ten weeks in splint Patient had a pathological dislocation of the hip due to a staphylococcic arthritis. Treatment in a plaster cast for three months resulted in the formation of extensive pressure sores which necessitated removal of the cast. Hip redislocated twenty four *hours after removal of cast and patient's condition became desperate* Because of the extensive pressure sores and the inadvisability of re casting, the hip was mechanically transfixed from the ilium to the femur Patient's general condition improved immediately The immobilization of the hip was so firm that patient had no further pain He could be moved about the bed to permit treatment of the pressure sores, and transported to the physiotherapy for ultraviolet irradiation Firm ankylosis of the hip resulted in ten weeks at which time all pressure sores were healed Patient was up and walking about twelve *weeks after application of the splint.*

A, Stader reduction splint applied *B*, Preoperative x ray film *C* Postoperative x ray view

SECTION VII

BONE GRAFTS

CHAPTER XXI

BONE GRAFTS

A thorough discussion of the subject of bone grafting is not within the scope of this text The method employed in our practice was one that permitted the adaptation of the mechanical features of the splint to the problem at hand The many problems confronting us in the past had to do mainly with the following

1 Technical difficulties of the operation itself
2 Difficulty in securely fixing the graft unless some form of internal fixation was used
3 Difficulty in maintaining rigidity of graft during convalescence
4 Difficulty with functional restoration, especially in old cases with marked impairment of function of adjacent joints

Application of the External Fixation Splint in Bone Grafting

Controlled external skeletal fixation acts as a reduction frame thus greatly simplifying the technical phase of the operation The graft may be securely held in place without added internal fixation of the graft by means of controlled impaction at the time of the operation as well as during the convalescence (Fig 93) With rigid fixation assured, active motion of the extremity is permitted for early functional restoration

Long wide full thickness bone grafts have been used, the ends of which are cut to form a long "V" (Fig 94) The "V" is beveled as is the site of implantation so that the

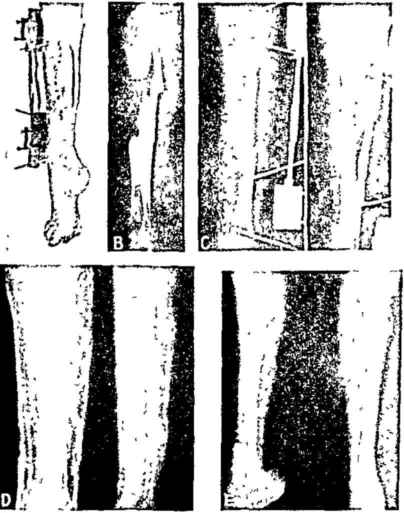


Fig. 93 (P. H.).—Nonunion of fracture of upper third of tibia in a man of fifty-three years; three unsuccessful operations with loss of 4 inches of bone. Bone graft from opposite tibia inserted after application of Stader splint. During the operation it was possible to lift up the entire leg by grasping the 7-inch full thickness graft with a forceps, without any internal fixation of the graft itself. The splint was removed after three months, at which time clinical and x-ray evidence of beginning bony union was present. The leg was then supported in a plaster splint. Firm bony union resulted in six months, although further protection was advised.

A, Stader reduction splint applied. *B*, Preoperative x-ray film. *C*, Postoperative x-ray film. *D*, Recent x-ray. Leg supported in plaster splint. *E*, Final x-rays six months after grafting.

graft will not slip when impaction is applied The graft bridges the bone defect and extends at least 1½ to 2 inches into each fragment The graft and graft bed are cut with the Albee circular saw

The splint is applied first assuring firm control of the bone ends during the operation Wide exposure of the bone is unnecessary because the splint acts as a reduction frame

Fig 94 —Anteroposterior and lateral views of healing of a long V shaped graft in the upper end of the tibia showing the osteogenic activity under the graft as well as at the site of the graft implant

obviating the need for bone holding forceps Extensive periosteal stripping impairs the blood supply of the bone and is therefore avoided Gentleness in handling of tissues is encouraged The splint is sufficiently rigid to permit chiselling, gauging sawing and cutting of the bone with no additional support of the fragments in the wound

The bone ends are first resected or freshened Then the graft bed is made as described above

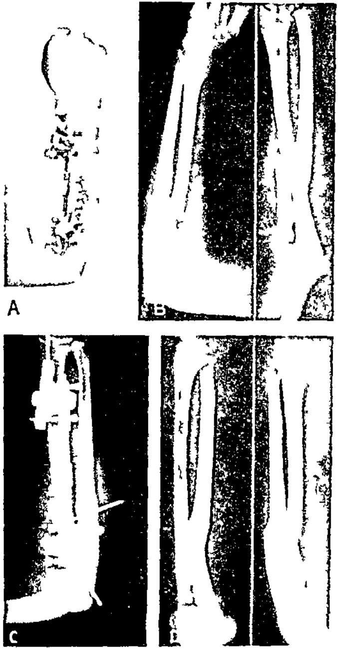


Fig 95.—A Nonunion of shaft of radius of nineteen years duration. Bone graft from tibia inserted after application of the splint. Graft impacted and no internal fixation of the graft was used. Free motion of wrist, fingers and elbow throughout period of healing. Firm bony union in fourteen weeks. *B* Preoperative x rays *C* Postoperative x rays with splint applied *D* Final x rays showing firm bony union.

The graft is then taken, usually from the anteromedial surface of the tibia, making certain that it is about 1 cm

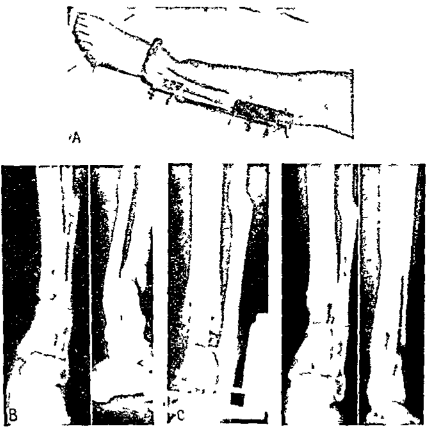


Fig 96 (A H).—Nonunion of fracture of lower end of left tibia with loss of bone substance in a sixty two year-old male, five years' duration He had had two previous operations, one a sliding graft and the other a bone plating operation, and both were followed by osteomyelitis and extrusion of the graft. The Stader reduction splint was applied and a full thickness tibial graft was inserted with no internal fixation

A, The splint applied *B*, Preoperative x ray film *C*, Postoperative x ray film *D*, X ray, four months after operation Union progressing but not solid

longer than the graft bed to allow for impaction A full thickness graft is used, and the medullary surface carefully

preserved The fragments are then distracted by activating the turnbuckle so as to permit the graft to slip into place, after which the fragments are apposed so as to firmly impact the graft in the bed If the ends of the graft have been properly shaped, they will fit snugly and will not slip out of place when the graft is impacted No additional internal *fixation of the graft is used*

Like bone is used in all cases, cancellous bone to come in contact with cancellous and cortical with cortical (see Fig 41)

A protective plaster splint has not been found necessary in any of the cases that came under our observation

In spite of the fact that the above procedure required firm impaction of the ends of the graft to secure them in place, *as well as the fact that grafts as long as 8 inches were* used, firm bony union occurred (Fig 94)

Advantages of Controlled External Fixation in Bone Grafting

The impressions gained from the application of controlled external skeletal fixation in bone grafting with the above method were

1 *Impaction of the graft is not harmful On the contrary* it is believed that firm impaction is the main factor in the success of the method
2 Grafts can be properly and successfully secured by external skeletal fixation without additional internal fixation of the graft
3 The rigid fixation of the extremity with freely movable adjacent joints is a factor in promoting growth of the graft
4 This method abides by the so-called three "inviolable' *rules for plant grafting*
   a The tissues must be applied like to like
   b The contact must be most intimate
   c They must be immobilized in that position (Albee).

SECTION VIII

INCIDENCE OF FRACTURES IN THE SERVICE

CHAPTER XXII

INCIDENCE OF FRACTURES IN THE SERVICE

About 70 per cent of battle casualties are wounds of the extremities and a high percentage of these cases are compound fractures In the first World War, it was estimated that 30 per cent of the wounded suffered from compound fractures Needless to say, all fractures in the service are not caused by combat

CAUSES OF FRACTURES IN THE NAVY AND MARINE CORPS

Fractures in the Navy and Marine Corps may be caused by combat, training, athletics and injuries sustained while men are on liberty.

1. Combat
   a. Bullets from machine gun, rifle, or revolver
   b Fragments and sharpnel from shells (artillery and trench mortars), torpedoes (aerial and marine), bombs, and grenades, mines (marine and terrestrial) and trench clubs (knobkerries)
   c Falls from explosions and direct injury by falling debris
2 Training (Naval and Military Hazards)
   Nautical, aeronautical, submarine and machinery hazards
3 Athletics and Recreative Sports
4. Leave and Liberty
   a. Vehicles
   b. Automobiles
   c. Motorcycles, etc.

Fractures sustained while men are on leave and liberty and those that occur as a result of injuries in athletics and recreative sports are in no way different from those incurred in civilian life Fractures sustained in combat are usually more extensive compound and frequently comminuted

There is more widespread tissue necrosis in war wounds and more extensive comminution of fractures than in civilian life All wounds should be considered infected and the wound tract is usually lined by devitalized and necrotic tissue The breach in skin is frequently less marked than in deeper structures where disruption may be considerable Reactionary edema is often present as a result of injury to soft tissues and outpouring of lymph into spaces This may be delayed for one or two days and if it takes place under the fascia it may jeopardize circulation

SECTION VIII

INCIDENCE OF FRACTURES IN THE SERVICE

CHAPTER XXII

INCIDENCE OF FRACTURES IN THE SERVICE

About 70 per cent of battle casualties are wounds of the extremities and a high percentage of these cases are compound fractures In the first World War, it was estimated that 30 per cent of the wounded suffered from compound fractures Needless to say, all fractures in the service are not caused by combat

CAUSES OF FRACTURES IN THE NAVY AND MARINE CORPS

Fractures in the Navy and Marine Corps may be caused by combat, training athletics and injuries sustained while men are on liberty

1 Combat
   a Bullets from machine gun rifle, or revolver
   b Fragments and sharpnel from shells (artillery and trench mortars), torpedoes (aerial and marine) bombs, and grenades, mines (marine and terrestrial) and trench clubs (knobkerries)
   c Falls from explosions and direct injury by falling debris
2 Training (Naval and Military Hazards)
   Nautical, aeronautical, submarine and machinery hazards
3 Athletics and Recreative Sports
4 Leave and Liberty
   a Vehicles
   b Automobiles
   c Motorcycles, etc

Fractures sustained while men are on leave and liberty and those that occur as a result of injuries in athletics and recreative sports are in no way different from those incurred in civilian life. Fractures sustained in combat are usually more extensive, compound and frequently comminuted.

There is more widespread tissue necrosis in war wound and more extensive comminution of fractures than in civilian life. All wounds should be considered infected and the wound tract is usually lined by devitalized and necrotic tissue. The breach in skin is frequently less marked than in deeper structures where disruption may be considerable. Reactionary edema is often present as a result of injury to soft tissues and outpouring of lymph into spaces. This may be delayed for one or two days and if it takes place under the fascia it may jeopardize circulation.

SECTION IX

ANESTHESIA; X-RAY STUDY

CHAPTER XXIII

ANESTHESIA IN THE TREATMENT OF FRACTURES

Lieutenant Commander Donald E Hale, MC-V(S), U S N R

The anesthetic methods and agents best suited to the treatment of fractures in war casualties are local infiltration, nerve block, spinal, intravenous, and open drop ether Other inhalation anesthetics may be used, but these will not be discussed here because the special equipment needed for their administration is not available aboard ship or in the field of battle

The choice of the anesthetic is determined by the location and condition of the operative site, the physical and mental condition of the patient, the anesthetic agents and equipment available and the skill of the anesthetist Thus, infiltration intravenous and ether anesthesia may be suitable for any fracture reduction, whereas the various nerve blocks and spinal anesthesia are applicable to certain regions only A patient in good physical and mental condition is a satisfactory subject for any of the methods, but a patient in or near shock, or one who is anemic (especially from recent hemorrhage) is not a candidate for intravenous or spinal but should preferably be given local infiltration anesthesia An unstable apprehensive patient may better be given intravenous or ether anesthesia, or one of the other agents with special care to insure adequate preanesthetic sedation The limitations imposed by the nature of the available equipment and the skill of the administrator are obvious Various substitutions for the equipment mentioned in this chapter may be made according to the apparatus available

PREANESTHETIC PREPARATION

Sedation

Ideal preanesthetic sedation allows the patient to be brought to the anesthetist conscious (or easily aroused) and cooperative but free from apprehension and indeed indifferent to the impending procedure The dosages of the drugs employed for this purpose vary chiefly with the weight nervous status physical condition and age of the patient Thus a patient light in weight free from apprehension in poor physical condition and beyond middle age requires smaller doses of preanesthetic drugs than an overweight nervous robust patient in his twenties

Pentobarbital should be given by mouth in doses of $1\frac{1}{2}$ to 3 grains two hours before the operation One half hour before the anesthesia is begun $\frac{1}{4}$ grain of morphine sulfate ($\frac{1}{6}$ to $\frac{1}{\text{[illegible]}}$ grain as minimum and maximum doses) should be given by hypodermic injection Atropine sulfate $\frac{1}{150}$ grain should be given with the morphine sulfate if intravenous or ether anesthesia is to be employed

In emergencies in which there is not sufficient time for the plan suggested above preanesthetic medication may be given satisfactorily by vein The morphine is given with or without atropine in sterile distilled water, slowly the injection being completed in not less than five minutes The pentobarbital may be given by the same route if available or pentothal sodium may be substituted for it as indicated under Intravenous Anesthesia"

CARE OF THE PATIENT DURING OPERATION

During the course of anesthesia the blood pressure, pulse rate and respiratory rate should be recorded at intervals of five minutes. This practice is recommended with all the types of anesthesia described in this chapter, but is of especial importance with the use of spinal pentothal and ether anesthesia. Such a record gives early evidence of changes in the condition of the patient and allows appropriate treatment when needed.

LOCAL INFILTRATION ANESTHESIA

Local infiltration is the injection of an appropriate local anesthetic solution into the tissues which sustain the trauma of operation.

Special Indications.—Local infiltration is the safest anesthesia for the treatment of fractures. It is especially valuable for the patient in poor condition from any cause such as dehydration, exhaustion, starvation, shock, hemorrhage or associated injury.

Contraindications.—The only specific contraindication to local infiltration anesthesia is a proved sensitivity of the patient to the drugs available.

A soiled or lacerated skin in the area to be injected is as much of a contraindication to the injection of anesthetic solution as it is to the insertion of transfixation pins. The injection is to be made through clean intact skin whenever possible. In the presence of burns or contamination, the skin must be adequately cleaned and debrided before insertion of either local infiltration needle or transfixation pin.

Agents and Equipment (see Fig. 97)

Procaine or metycaine, 0.5 per cent solution
Epinephrine, 1 cc of a 1:2600 solution
Beaker, 250-cc capacity
Syringe, 10-cc Luer Lok
Needles
- 2 hypodermic, ½-inch, 26-gauge
- 2 local infiltration, 2 inch, 22 gauge
- 2 local infiltration, 3 inch, 22-gauge

Skin antiseptic solution
Sterile towels and drapes

The anesthetic solution may be prepared by adding 1 gm. of the crystals (procaine or metycaine) to 200 cc. of boiling fresh physiological saline solution, and allowing to cool. Another method is to add the contents of a 5-cc. ampule of 20 per cent procaine or metycaine to 195 cc. of sterile physiological saline solution. One cubic centimeter of 1:2600 epinephrine, or six drops of the 1:1000 solution may be added to prolong the duration of the anesthesia if desired, but none should be used in the presence of hypertension or hyperthyroidism.

Technique (see Fig. 98)

The patient should be placed on the operating table and the operative site prepared and draped for the surgical procedure. If the skin is soiled or greasy it should be scrubbed with soap and water before the application of the skin antiseptic. If the fracture site is sensitive, the first step must be the injection of this region. In fresh simple fractures (within six to eight hours) this is most readily accomplished by injecting the solution into the still fluid hematoma which bathes the fragment ends. One of the longer needles is inserted through the skin (without raising a preliminary wheal) and advanced until it strikes the side or end of one of the fragments. Aspiration is attempted and, if need be, the needle is manipulated by repeated partial withdrawals, change of direction and advancement until positive evidence of its having entered the hematoma is elicited by the fact that bloody fluid can be drawn into the syringe. When this is achieved, from 10 to 30 cc. of the anesthetic solution is injected. If the hematoma is no longer fluid, an annular zone of infiltration must be laid down about the fragment ends. To accomplish this one of the longer needles (depending on the size of the extremity) is inserted through each of two points at opposite ends of the horizontal (i.e., lateral instead of anteroposterior) diameter of the extremity, at the level of the fracture. The solution is deposited in a zone which surrounds the fracture site completely, the needle being several times redirected and contacting the bone at the end of each stroke except

anterior and posterior to the bone where the needle is tangential to this structure Thirty to 50 cc of the solution is used for this procedure, and the injection is carried out while the needle is in motion as well as while it is in contact with the bone

If the fracture is compound the anesthetization of the fracture site must be accomplished by injecting the solu

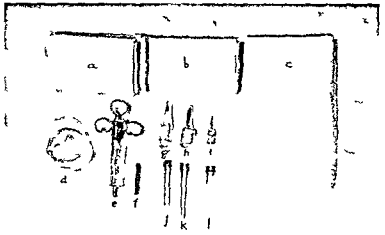


Fig 97—*Local Infiltration Tray* *a* *b* Sterile towels *c* sterile drape *d* 250-cc. beaker containing 195 cc of physiological saline solution *e* 10-cc Luer Lok syringe *f* ampule file *g* 5 cc of 20 per cent metycaine *h* 5 cc of 20 per cent novocain (procaine) *i* 1 cc of 1 2000 epinephrine (6 minims of a 1 1000 solution) *j* local infiltration needles 2 inch 22 gauge *k* local infiltration needles 2½-inch 22 gauge *l* hypodermic needles ¼-inch 26 gauge

tion at a level at least 1½ inches above the most proximal extent of the wound

An intradermal wheal is raised by injecting the procaine solution through the hypodermic needle at the site of the proposed insertion of the first pin of the external fixation apparatus This wheal should be made about 1 cm in diameter, and produces immediate skin anesthesia One of the longer needles is then attached to the syringe and 10 to 20 cc of the solution is used to inject the tissues be

tween the skin and the bone along the path which the pin is to take. Special care must be taken to inject thoroughly the periosteum, as this structure, except for the skin, is the most sensitive tissue to be encountered.

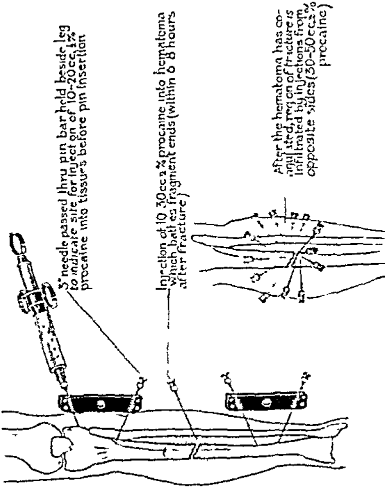


Fig 98 Technique of local infiltration anesthesia

After the first injection, the first pin is inserted. The injection for the second pin can then be made accurately, as the second hole in the pin block indicates the point at which the skin is to be perforated, and the direction of the pathway to the bone.

The injection for the third and fourth pins is carried out in the same manner as that for the first two pins.

If desired, the injection for all four pins may be made before any are inserted, but wider zones of injection are then needed, as the sites cannot be judged as accurately as by the other method

If the operative procedure proves to take longer than anticipated, additional injections may be made during the procedure in order to extend the period of anesthesia

Supplementation

Restlessness and nervousness of the patient may be allayed by the injection of additional doses of morphine sulfate hypodermically or intravenously or by small intravenous injections of pentothal sodium

NERVE BLOCK

Brachial plexus block and nerve block at the elbow are the two procedures available for anesthesia of the upper extremity

Special Indications —Nerve block, when successful, gives a more complete anesthesia than does local infiltration Next to infiltration it is the safest method for the poor risk patient The brachial block is satisfactory for treatment of fractures of the humerus, ulna or radius, but the elbow block can be used only for forearm fractures

Contraindications —Nerve blocks cannot be used in patients sensitive to the drugs at hand, nor can they be used when the skin or other structures at the site of injection are damaged, badly soiled, or burned

Agents and Equipment (see Fig 99)

Procaine or metycaine, 0 5 per cent and 2 per cent solutions
Beakers, 150 and 250-cc. capacity
Syringe, 10-cc. Luer Lok
Needles
  2 hypodermic, ½-inch, 26-gauge
  2 local infiltration, 1½-inch 22 gauge
  4 local infiltration 2¼-inch 22 gauge
Twelve- or 18 inch length of small-caliber rubber tubing fitted with glass needle adapter at one end and metal syringe adapter at the other (for brachial block)
Skin antiseptic solution
Sterile towels and drapes

The anesthetic solution is prepared by adding 1 gm. of the crystals (procaine or metycaine) to 50 cc. of fresh boiling physiological saline solution, or by adding 5 cc. of 20 per cent procaine or metycaine to 45 cc. of sterile physiological saline. The 2 per cent solution is placed in the 150-cc. beaker and the physiological saline solution in the 250-cc. beaker. The 0.5 per cent solution is prepared in the syringe by aspirating 2.5 cc. of 2 per cent solution and 7.5 cc. of physiological saline solution.

Technique of Brachial Plexus Block (see Fig. 100)

The patient is placed on his back. The shoulder on the side of the fracture is drawn downward and the head is turned away from this side. An area about 12 inches in diameter with its center at the midpoint of the clavicle is prepared with a skin antiseptic, and the area is draped. An intradermal wheal is raised 1 cm. above the midpoint of the clavicle. Palpation downward, backward and inward at this point discloses the resistance afforded by the first rib, which meets the clavicle at a few degrees less than a right angle. If the palpating finger is passed along the long axis of the rib with considerable pressure, it may be able to feel the components of the brachial plexus. Palpation deep behind the clavicle toward the anterior extremity of the first rib *may or may not reveal the pulsation of the subclavian artery.*

The 2½-inch needles are checked for patency of the lumen by injecting a few drops of fluid through each. One of them is fixed to the glass adapter of the small-caliber rubber tubing and the syringe, filled with solution, to the metal adapter in the other. The syringe is laid in the angle *between the patient's head and shoulder, or on a nearby* sterile-topped table so that the needle reaches readily to the supraclavicular wheal. The needle is thrust through the wheal *and is directed downward, backward and inward toward the superior surface of the first rib. If the subclavian artery can be felt, the needle should be passed just above and lateral to it.* As the needle is advanced slowly, the patient is asked to report immediately any lightning-

like sensation in his arm forearm or hand As soon as such a stimulus has occurred the barrel of the syringe is with drawn slightly and the glass connector (which is attached to the needle) is observed for evidence of aspirated blood If none appears 10 cc. of the anesthetic solution is injected slowly with two or three recheck aspirations during the process It is important that the point of the needle be held

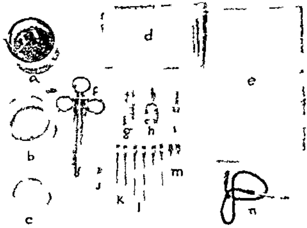


Fig 99—*Brachial Block and Nerve Block Tray* *a* Skin antiseptic solution *b* 2o0-cc beaker containing 100 cc of physiological saline solution *c* 150-cc beaker containing 45 cc of physiological saline solution *d* sterile towels *e* sterile drape *f* 10 cc Luer Lok syringe *g* 5 cc. of 20 per cent metycaine *h* 5 cc of 20 per cent novocain (procaine) *i* 1 cc of 1 2600 epinephrine (6 minims of a 1 1000 solution) *j* ampule file *k* local infiltration needles 1¼-inch 22 gauge *l* local infiltration needles 2¼-inch 22 gauge *m* hypodermic needles ½-inch 26-gauge *n* rubber tubing with needle adapter (glass) and syringe adapter (metal)

stationary during the injection since a dislodgment of as little as a millimeter may result in the placing of the solution into a fascial space other than the one in which lie the trunks of the brachial plexus The rubber tubing which allows free mobility of the needle and still permits immediate injection after checking against an intravascular position of the needle point facilitates this procedure

The injection of 10 cc of the solution among the trunks

of the plexus may give satisfactory anesthesia in fifteen to twenty minutes. If it does not do so, additional injections may be made as indicated below.

If the first needle fails to yield a paresthesia before it makes contact with the first rib, it is left with its point

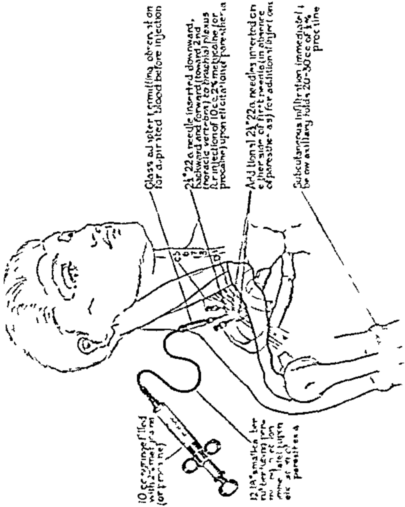


Fig 100 Technique of brachial plexus block.

in contact with that structure, and the rubber tubing (with glass adapter) is disengaged from it. Another needle is fixed to the adapter and is inserted parallel to the first needle and 0.5 cm. anterior and medial to it, i e., closer to the subclavian artery. If this needle elicits a paresthesia

while being advanced its progress is immediately arrested and an injection is made as described above If it does not, it is advanced until its point reaches the rib whereupon it is detached from the adapter and left in position A third needle is attached to the adapter and advanced parallel to the other two and in an axis 0 5 cm posterior and lateral (i e farther away from the subclavian artery) to the first needle This is essentially the Knight modification of the Kulenkampf method (quoted by Lundy) If this needle also fails to elicit paresthesia before reaching the rib, it is re tracted about 3 mm from the rib and 3 5 cc of the solution is injected, the needle is retracted another 3 mm and an other 3 5 cc injection is made After retraction for another 3 mm, the remainder of the solution (3 cc) in the syringe is injected, and the needle is withdrawn Ten cubic centimeters of solution is injected similarly through the other needles and the region is then vigorously massaged for five minutes

If the anesthesia is inadequate or incomplete at the end of twenty minutes following the last injection, the proced ure may be repeated or it may be supplemented as indicated under "Supplementation"

When brachial plexus block is used for procedures upon the humerus it must be supplemented by a subcutaneous ring of anesthesia (20 to 30 cc of 0 5 per cent procaine or metycaine) encircling the arm immediately distal to the axillary folds

Technique of Nerve Block at the Elbow (see Fig 101)

The patient is placed upon his back The region about the elbow is prepared with a skin antiseptic, and the upper extremity is draped and laid in the position of supination upon an arm board The median, radial and ulnar nerves are blocked

The median nerve at the transverse crease in the cubital fossa is adjacent and medial to the brachial artery, the pulsations of which can be felt 0 5 cm medial to the border of the biceps tendon The nerve can be palpated in many cases A wheal is raised in the skin over the nerve, and

through it is advanced a 1½-inch, 22-gauge needle attached to the syringe filled with a 2 per cent procaine or metycaine solution. Having pierced the deep fascia the needle is advanced with changes in direction as needed until it makes

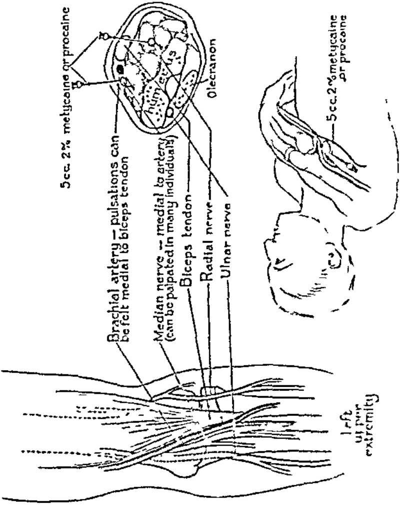


Fig. 101.—Technique of nerve block at the elbow

contact with the nerve as indicated by paresthesia radiating into the palm of the hand. Five cubic centimeters of the solution is injected in the vicinity of the nerve.

At the same level (cubital fossa crease) the radial nerve lies 0.5 cm. anterior to the lower end of the humerus, and

0.5 cm medial to its outer border. The intradermal wheal is raised 1 cm lateral to the outer border of the biceps tendon, and through it the 1½-inch needle is passed at right angles to the skin. Paresthesias (especially of the radial side of the back of hand) are elicited, and 5 cc of the 2 per cent solution is injected. If the needle strikes the humerus it has advanced too far, if it passes beyond the humerus it has been directed too far laterally, and must in either case be redirected.

For injection of the ulnar nerve the upper extremity is placed so that the forearm is held horizontally a few inches above the patient's chest. Resterilization of the skin and redraping are usually needed for this position. The nerve can be palpated as it enters the hiatus between the medial epicondyle of the humerus and the olecranon process of the ulna. A wheal is raised 1 cm proximal to this hiatus, and through it is passed a 1½-inch, 22-gauge needle attached to the solution filled syringe. The needle approaches the nerve at a very acute angle, and the injection of 5 cc of the 2 per cent solution is made when paresthesias referred to the fifth finger and hypothenar eminence have been elicited.

Following the blocking of the three nerves at the elbow, the upper forearm, immediately distal to the cubital fossa crease, is encircled by the subcutaneous injection of 10 to 20 cc of 0.5 per cent procaine or metycaine.

Supplementation

Failing anesthesia during a prolonged procedure may be supplemented by local infiltration. Hypodermic or intravenous injections of morphine sulfate may be used to control moderate discomfort or restlessness. Intravenous pentothal sodium may be used to good advantage when needed.

SPINAL ANESTHESIA

Special Indications.—Single injection and especially continuous (Lemmon) spinal anesthesia are satisfactory for the treatment of fractures of the lower extremity including the pelvic girdle. The relaxation afforded by spinal anes-

thesia is not exceeded by that of any other method. This makes it particularly valuable under circumstances which demand that spasm of large muscle masses, such as those of the thigh and gluteal region, be abolished. The shorter procedures may be managed under single injection spinal anesthesia, but compound fractures demanding wound débridement, or those which may require manipulation under the fluoroscope are best done under continuous spinal anesthesia. The continuous method is the safest form of spinal anesthesia, since the tolerance of the patient is elicited by his reaction to the initial injection of a small dose of procaine. The procedure can be continued as long as needed without the danger of a large single dose of the drug.

Contraindications.—Arterial hypotension from shock or other cause, anemia, cyanosis and dyspnea, because the depression of cell respiration accompanying them is aggravated by the fall in blood pressure which customarily accompanies spinal anesthesia, are the chief contraindications to the use of this method. This depression of cell respiration leads to serious consequences, particularly in its effect in disturbing the function of the vital centers (in the floor of the fourth ventricle) and the heart muscle. A marked hypertension is also a contraindication, because a fall in blood pressure from a high systolic reading, as for example above 200 mg. of mercury, to levels which ordinarily are considered normal, produces, in these individuals, a condition readily leading to shock. Unless the systolic blood pressure is between 90 and 200, spinal anesthesia should not be used.

Anemia of a degree signified by a hemoglobin of 50 per cent (7.9 gm. per 100 cc. of blood) or less, especially of recent acute origin, is a contraindication to the use of spinal anesthesia.

Additional contraindications are any conditions which render insertion of the spinal needle impossible or unsafe (such as fracture or disease of the spine, injury or infection of the skin of the region, etc.) and sensitivity of the patient to the drug.

Agents and Equipment for Single Injection Spinal Anesthesia (see Fig. 102). (For Continuous Spinal Anesthesia, see p. 218)

Procaine crystals, 150 mg ampule
Ephedrine sulfate, 1-cc. ampule (50 mg)
Syringes, 2 cc., 5-cc.
Needles
 2 hypodermic, ½-inch, 26-gauge
 2 local infiltration, 1½-inch, 22 gauge
 2 mixing, 2-inch, 18 gauge
 2 steel spinal, 3-inch and 3½-inch, 19- or 20-gauge
Ampule file
Skin antiseptic solution
Sterile perforated spinal tap sheet (3 feet square containing a central circular opening 6 inches in diameter)

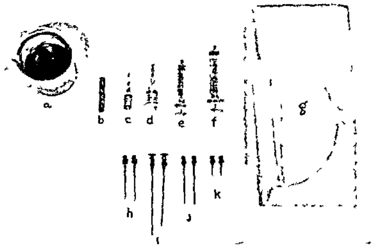


Fig 102—*Single Injection Spinal Tray* *a*, Skin antiseptic solution, *b*, ampule file, *c*, ephedrine sulfate, 1 cc. (50 mg), *d*, procaine crystals, 150 mg; *e*, 2-cc. syringe; *f*, 5-cc. syringe; *g*, spinal sheet; *h*, local infiltration needles, 1½-inch, 22 gauge; *i*, steel spinal needles, 3- and 3½-inch, 19- and 20 gauge; *j*, mixing needles, 2-inch, 18-gauge; *k*, hypodermic needles, ½-inch, 26-gauge.

Technique of Single Injection Spinal Anesthesia (see Fig. 103). (For Continuous Spinal Anesthesia, see p. 219)

1. *Position.*—The patient is placed on his right or left side on the operating table. The knees are drawn as close to the chin as possible, and the plane of the back is placed at right angles to the plane of the operating table.

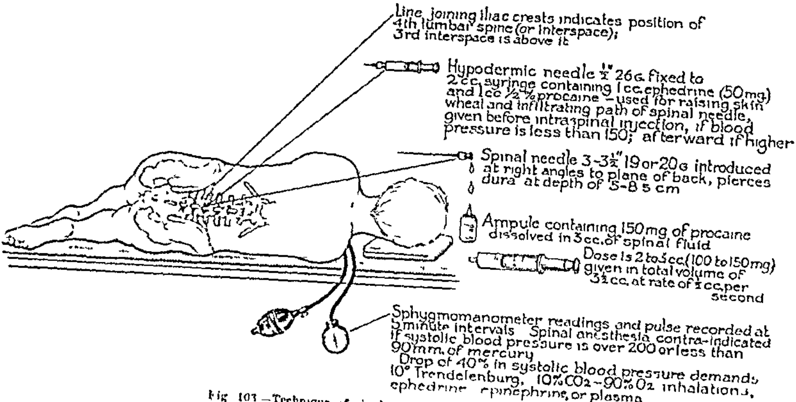


Fig 103 —Technique of single injection spinal anesthesia

2 *Preparation of Site of Spinal Tap*—A wide area over and about the site of puncture is painted with a skin antiseptic solution Over this is laid the perforated spinal tap sheet

3 *Location of Puncture Site*—An imaginary line connecting the iliac crests crosses the spinal column at the level either of the 4th lumbar interspace (the space between the 4th and 5th lumbar vertebrae) or of the 4th lumbar spinous process The space above this (the third lumbar interspace) is thus identified as the site of the spinal tap

4 *Anesthetization of Puncture Site and Injection of Ephedrine*—A mixture of 1 cc of 0 5 per cent procaine (without adrenalin) and 0 5 cc (25 mg) of ephedrine in the 2-cc syringe is used to raise a wheal in the skin of the midline over the spinal interspace selected The path to be taken by the spinal needle is infiltrated with the solution to a depth of about 1 inch using the 1½ inch 22 gauge needle The remainder of the solution is injected through the same wheal but laterally into the erector spinae group of muscles so that the whole amount of ephedrine is given If the systolic blood pressure is over 150 mm of mercury the ephedrine is given after the intraspinal injection of procaine This precaution is taken in order to avoid raising an already elevated arterial tension in the event that spinal tap is prevented by unforeseen technical difficulties

5 *Spinal Tap*—The spinal needle is inserted at right angles to the skin surface and is cautiously advanced until the dural puncture is felt at a depth varying between 5 and 8 5 cm If the dural puncture is not felt the stylet of the needle should be withdrawn to check for spinal fluid after a depth of 5 cm has been reached The stylet is then replaced and the needle advanced additional distances of 0 5 cm between such withdrawals (of the stylet) until spinal fluid drips from the needle If a solid obstruction (bone) is encountered before spinal fluid appears the needle must be partially withdrawn and redirected upward or downward (cephalad or caudad) Observation of the needle in place from a distance of 4 to 6 feet may indicate that the needle is directed slightly toward one side If adjustments

still fail to yield spinal fluid, another interspace may be used and as a last resort the patient may be placed in a sitting posture, which facilitates the procedure If a unilateral paresthesia such as shooting pain in one knee or ankle occurs while the needle is being placed it indicates that the needle point is directed toward the side of the paresthesia and that it should be directed slightly toward the opposite side

6 *Making the Injection* —About 2 cc of spinal fluid is allowed to drip into the ampule containing 150 mg of procaine crystals When the crystals have been dissolved by aspirations into and expulsions from the 5-cc syringe with the mixing needle attached the solution is aspirated into the syringe The stylet of the spinal needle is removed the syringe is connected and sufficient spinal fluid is aspirated to bring the volume in the syringe to 3 cc Each cubic centimeter of this solution contains 50 mg of procaine The dose is selected (2 to 3 cc containing 100 to 150 mg) according to the age weight and height of the patient and the expected duration of the operation Thus more of the drug is used in a young subject weighing 200 pounds and for a time-consuming procedure than for an older, smaller individual undergoing a shorter operation The solution in excess of that containing the selected dose is ejected from the syringe The syringe is then reconnected to the spinal needle, additional fluid is aspirated to give a total volume of 3 5 cc and the injection is made at the rate of 0 5 cc per second At the end of the injection 0 1 cc is aspirated to make certain that the point of the needle is still within the dural sac, and this amount is then reinjected The needle still attached to the syringe is withdrawn the puncture site is covered by a small prepared adhesive dressing and the patient is turned upon his back

7 *Care during Operation* —Blood pressure pulse and respiration readings are taken and recorded at five-minute intervals A drop in systolic blood pressure of 15 to 20 mm of mercury is common and is no cause for alarm The systolic pressure should not be allowed to fall more than 10 per cent below the preanesthesia level Lowering the head of the

table 10 degrees and the administration of a mixture of 10 per cent carbon dioxide and 90 per cent oxygen will counteract to some extent a drop in blood pressure Ephedrine in 3- or 4-minim amounts may be injected intravenously as needed, but a total of 100 mg (including the 25 mg given before the subarachnoid injection) should not be exceeded Neosynephrin and epinephrine may be given in 1 to 5- minim doses intravenously in the case of urgent need The subcutaneous injection of these drugs in the presence of a marked fall in blood pressure is of less value, since the peripheral circulation is too slow to carry them into the blood stream A prolonged (fifteen to twenty minutes) unresponsive fall in blood pressure should be treated by the infusion of plasma or of whole blood

8 *Postoperative Care*—When returned to bed, the patient should be placed in a level position with instructions not to raise the head for twenty-four hours If the blood pressure is below the previous resting level the foot of the bed should be elevated 8 or 10 inches until it returns to normal

Agents and Equipment for Continuous Spinal Anesthesia (see Fig 104)

Procaine crystals, two 150 mg ampules
Ephedrine sulfate, 1-cc ampule (50 mg)
Syringes, 2-cc , 10 cc Luer Lok type
Rubber tubing, 3 foot length nonelastic, small caliber, capacity 2 cc fitted with Luer Lok stopcock syringe connector at one end and with Luer Lok needle connector at the other
Needles
- 2 hypodermic, ½ inch, 26-gauge
- 2 local infiltration, 1½-inch, 22 gauge
- 2 mixing 2 inch, 18 gauge
- 1 Sise introducer
- 2 German silver malleable continuous spinal needles, 3-inch and 3½-inch, 17- or 18 gauge

Ampule file
Adhesive tape, strips 2½ by 6 inches (4 strips)
Special mattress, 5 inches in thickness with portion cut out to accommodate the spinal needle in place Several sheets folded and laid transversely across the usual operating table mattress, so as to elevate the dorsal spine may be used as a substitute

Technique of Continuous Spinal Anesthesia (see Fig. 105)

1. *Position.*—The patient is placed on the special mattress, at first supine in exactly the position he is to occupy during the operation, and is then rolled onto his left side *so that he rests on the edge of the mattress. This allows a* return to the proper position with a minimum of movement. The knees are approximated to the chin and the plane of the back is placed at right angles to the plane of the operating table. *The placing of a litter having the same height* as the spinal mattress beside the operating table to support the flexed lower extremities of the patient facilitates maintaining the ideal position.

The information regarding location and preparation of the site of spinal tap, and the *use of the ephedrine* is given under the technique of single injection spinal anesthesia.

2. *Spinal Tap.*—The skin and intraspinous ligament are *punctured at the interspace selected by means of the Sise* introducer or a steel needle of the caliber of the continuous spinal needle. Through the opening thus provided the malleable spinal needle is inserted and advanced until its *point perforates the dura. During this maneuver, it is im*portant that no force be exerted except in the long axis of the needle, as it bends easily. If the first thrust of the needle does not yield spinal fluid, it must be partially with*drawn and redirected.*

3. *The Anesthetic Solution.*—Three hundred milligrams of procaine crystals are dissolved in 10 cc. of spinal fluid (by the method described under the single injection technique on page 217) *or in* sterile physiological saline solution. Each cubic centimeter of this solution cantains 30 mg. of procaine.

4. *Making the Injection.*—After the solution has been thoroughly mixed in the syringe, the small-caliber, nonelastic rubber tubing is connected to the syringe. A sufficient quantity of solution to fill the tubing is expressed from the syringe and the stopcock on the syringe end of the tubing is closed. The spinal sheet is carefully lifted from the patient's back, and the rubber tubing is connected to the spinal needle. After determining that aspiration of fluid is free, the

patient is turned onto his back, care being exercised to avoid twisting the spine, and making certain that the needle and tubing are accommodated in the defect of the mattress If, at this point, aspiration is free, the first injection may be made If aspiration is not free, it may in some cases be made so by turning the needle on its long axis, or by slightly advancing or retracting it, intermittent attempts being made to aspirate

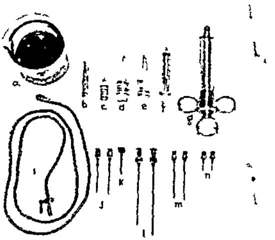


Fig 104—*Continuous Spinal Tray* *a*, Skin antiseptic solution, *b* ampule file, *c*, ephedrine sulfate, 1 cc (50 mg), *d*, *e*, 150 mg ampules of procaine crystals *f*, 2-cc syringe, *g* 10-cc Luer Lok syringe, *h*, spinal sheet, *i*, 3 foot rubber tubing, 2-cc. capacity, with stopcock, *j*, local infiltration needles 1¼-inch 22 gauge, *k*, Sise introducer, *l* German silver malleable spinal needles, 3 and 3½-inch 17- and 18 gauge, *m*, mixing needles, 2 inch, 18 gauge, *n*, hypodermic needles ½-inch, 26-gauge

If these devices for obtaining aspiration fail, the patient must be turned on his side and the needle replaced, preferably in an adjacent interspace The possibility of the necessity for replacing the needle exists in every case On this account, it is wiser not to make the first injection as soon as the tubing is connected to the spinal needle, while the patient is still on his side, because the additional changes

in position incident to replacing the needle after anesthesia has been induced may prove shocking to the patient.

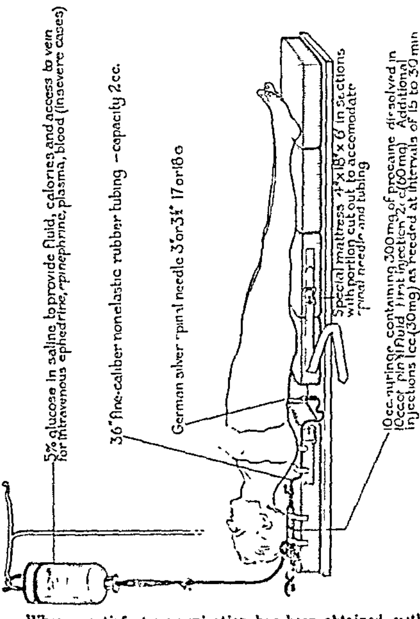


Fig 105 Technique of continuous spinal anesthesia

When a satisfactory aspiration has been obtained, with the patient on his back, the syringe is secured beside the

patient's head to the sheet covering the mattress by means of two ½ by 6 inch strips of adhesive tape, and the connecting tubing is secured to the side of the mattress by similar means

The first injection should be 2 cc (60 mg) of solution Subsequent injections of 1 cc (30 mg) may be made at intervals of fifteen to thirty minutes, as needed to keep the patient free from discomfort

5 *Care of Patient during and after Operation* —In addition to the previous suggestions for the care of patients receiving the single injection spinal anesthetic, the administration of an intravenous infusion of 5 per cent glucose in normal saline should be given to patients with serious fractures or those in whom shock may be expected This helps to maintain salt and water balance supplies a few calories, and affords a continuously open vein, if needed for the administration of circulatory stimulants (ephedrine, epinephrine), plasma or blood

Supplementation

Spinal anesthesia may be supplemented by the use of local infiltration anesthesia Additional injections of morphine sulfate (hypodermically or intravenously) may be required in long operations

Intravenous pentothal sodium and rarely ether may be used to supplement spinal anesthesia Even when the analgesia is obviously adequate the use of morphine sulfate or pentothal sodium may be valuable for apprehensive or demoralized patients

INTRAVENOUS ANESTHESIA

Special Indications —Intravenous anesthesia is of value for patients who are in good physical condition but who are unsuited for local infiltration nerve block, or spinal anesthesia by reason of a state of mental agitation It is of benefit also as a supplement to the methods mentioned previously either to increase the degree of analgesia or in smaller amounts simply to extend the effect of the preanesthetic sedation

Contraindications.—Shock, anemia, cyanosis, any obstruction to the respiratory passages and chronic disorders of the lungs are contraindications to the use of intravenous anesthesia. Pentothal sodium depresses the respiratory center and this may result in hypoxemia in the presence of the conditions mentioned.

Additional contraindications are untoward reaction to the drug (in a previous administration) and the inability to find a vein suitable for the injection.

Agents and Equipment (see Fig. 106)

- Pentothal sodium 0.5 gm. or 1.0 gm. ampules
- Sterile distilled water 10- or 20-cc. ampules
- Syringes: two 20-cc., one 2-cc.
- Needles:
  - 2 intravenous 1¼-inch 21 gauge
  - One 2 inch 18 gauge
- Ampule file
- Rubber tubing 2 feet in length, small caliber, with syringe adapter at one end and needle adapter at other (preferably with stopcock on syringe connector if to be used without syringe holder)
- Syringe holder: Rudder (optional)
- Rubber pharyngeal airway
- Skin antiseptic
- Arm board 8 inches by 3 feet, padded
- Bandage 3 inch gauze or muslin (or adhesive strip 2 by 12 inches)
- Adhesive tape 2 strips ½ inch by 4 inches, 2 strips ¼ inch by 14 inches

Technique (see Fig. 107)

1. *Position of Patient*.—The patient is placed on his back on the operating table. It is important to secure the extremities of the patient so that no movement is allowed in the event that he is aroused by a stronger stimulus than the stage of anesthesia can control. This is best accomplished by passing a snug band above the knees (or over the sound limb only if one is to be operated upon), and by fixing the upper extremity not used for the intravenous injection to the side of the patient, or on an arm board if it is the site of the operation.

2. *Preparation of Solution*.—Pentothal sodium is used in a 2.5 per cent solution. This is prepared by dissolving the

contents of the 0 5 gm (7½ grain) ampule in 20 cc or of the 1 0 gm (15 grain) ampule in 40 cc of sterile distilled water The solution unless crystal clear must be discarded The 20-cc syringe is filled with the solution and then it is attached to the length of fine caliber rubber tubing which is in turn filled from the syringe

3 *The Venipuncture.*—The upper extremity selected for the venipuncture is laid in the position of supination on

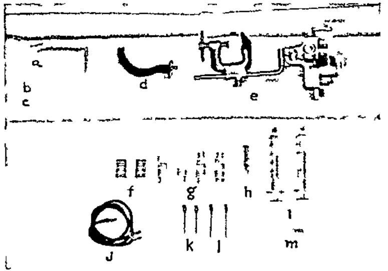


Fig 106.—*Pentothal Sodium Tray* *a* 3 inch roller bandage *b* adhesive ¼ by 4 inches *c* adhesive ¼ by 14 inches *d* pharyngeal airway, *e* Rudder syringe holder *f* pentothal sodium 0 5 gm ampules *g* sterile distilled water 10-cc ampules *h* 2-cc syringe *i* 20 cc syringes *j* rubber tubing 24 inch length with stopcock *k* intravenous needles 1½-inch 21 gauge *l* mixing needles 2 inch 18 gauge *m* ampule file

the arm board It is secured by a strip of adhesive tape 2 by 20 inches which is laid across the palm and is snugly overlapped beneath the board or by several turns of a 3 inch gauze or muslin bandage over the wrist (the first two turns not to include the arm board) A tourniquet is applied above the elbow, but not tightly enough to obliterate the pulsations of the radial artery An appropriate forearm or cubital fossa vein is selected and the skin covering it is

cleansed with an alcohol sponge The intravenous needle fixed to the 2-cc. syringe is then passed through the skin

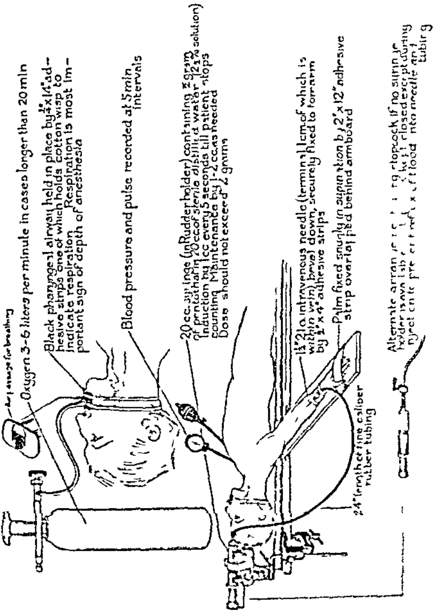


Fig 107 Technique of intravenous anesthesia

and into the vein. The presence of the tip of the needle within the lumen of the vein is tested by aspirating blood

into the syringe The needle is then advanced so that at least a half inch of its length lies within the vein The tourniquet is loosened, the syringe is removed, the adapter on the rubber tubing is connected to the needle, and both are secured to the forearm by means of two ½-inch by 4 inch strips of adhesive tape The syringe is then placed in the Rudder syringe holder which is clamped to the head of the operating table or to the arm board If the Rudder holder is not available, the syringe (with stopcock connector) is fixed to one of the sites suggested above by adhesive tape The stopcock, except during injection of solution is kept closed to prevent blood from flowing into the tubing

4 *Induction of Anesthesia*—False teeth, if present, are to be removed The 2 5 per cent solution of pentothal sodium (in distilled water), containing 25 mg per cubic centimeter, is injected at the rate of 1 cc every five seconds until the patient stops counting Thereupon, thirty seconds are allowed to elapse so that the full effect of the drug may be noted This amount of the drug provides adequate supplementation of the methods described earlier in the chapter provided that the analgesia of the other method (local, infiltration, nerve block, or spinal) is adequate and a diminishing of the apprehension or alertness of the patient is all that is desired This state may be perpetuated by the subsequent injection of 1 or 2 cc quantities when needed as indicated by an increasing awareness of the patient

If surgical anesthesia is desired additional 1- or 2-cc quantities are injected at 30 second intervals until the rubber pharyngeal airway can be inserted This may be secured by passing over it two strips of adhesive tape (¼ by 14 inches) which reach backward to below the ear Under one of them, as it passes the opening in the airway, is fixed a small wisp of cotton to act as an indicator of respiration It is essential that a patent airway and free respiration be maintained during anesthesia The surgeon now tests the depth of the anesthesia by giving the patient a painful stimulus such as a pinch with a towel clip or the prick of a needle If the patient responds additional 1- or 2 cc quan-

tities of the solution are injected at 30-second intervals until the insertion of the first pin can be begun The anesthesia is maintained by injecting 1 or 2 cc of the solution as needed Movements of the patient or evidence of reaction to the pharyngeal stimulation of the airway (swallowing gagging) are reliable indications of lightening of the anesthesia Except under special conditions, the dose should not exceed 2 gm Whenever possible the use of pentothal sodium should be accompanied by the administration of 3 to 6 liters per minute of oxygen by nasal catheter (to oropharynx), mask, or other means

5 *Postanesthetic Care*—The patient must have constant supervision, with especial care that the airway remain patent until recovery from the anesthesia When the patient is able to answer questions he can usually be considered as safe from this standpoint

Supplementation

Local infiltration of 0 5 per cent procaine into the fracture site and into the skin and periosteum perforated by the pins allows the use of much smaller (and often therefore safer) quantities of pentothal sodium

ETHER ANESTHESIA

Ether is the only inhalation anesthetic that will be discussed in this chapter, for the reason that is is almost universally available and that it is the safest agent for the induction of general anesthesia Its safety is owing in part to the fact that deep anesthesia causes cessation of respiration before the heart stops beating

Special Indications—When general anesthesia is considered necessary, as in a patient of high nervous irritability, and a contraindication to the use of pentothal exists ether may often be used with success If, however, contraindications to the use of ether exist, local infiltration or block anesthesia with careful attention to preanesthetic sedation must be the method of choice Circumstances may exist under which ether is the only available anesthetic.

Contraindications—Acute infections of the respiratory

tract chronic diseases of the lungs such as tuberculosis and bronchiectasis and advanced disease of the liver or kidney are contraindications to the use of ether Ether should not be used in the presence of open flame and often cannot be used in the presence of excessive heat (boiling point 96° F)

Agents and Equipment (see Fig 108)

Ether unopened ¼ pound cans
Wire mask covered with 12 layers of surgical gauze
Castor or mineral oil sterile for the eyes
Rubber pharyngeal airway
Damp towels one to protect the eyes another to wrap about the gauze covered mask

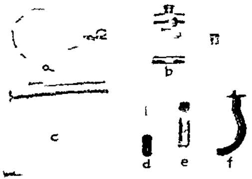


Fig 108 *Ether Tray* *a* Ether mask *b* ether ¼ pound *c* towels *d* medicine dropper *e* mineral or castor oil *f* pharyngeal airway

Technique (see Fig 109)

The patient is placed on his back on the operating table and is secured by a band above the knees and by fixing his arms to one of which the sphygmomanometer cuff is applied to the sides Into each eye is placed a drop of sterile oil and they are covered with a damp towel The gauze covered mask is placed gently over nose and mouth The ether can is prepared to deliver its contents drop by drop either by impaling its top with a safety pin or by cutting out the seal and inserting the cork grooved along opposite

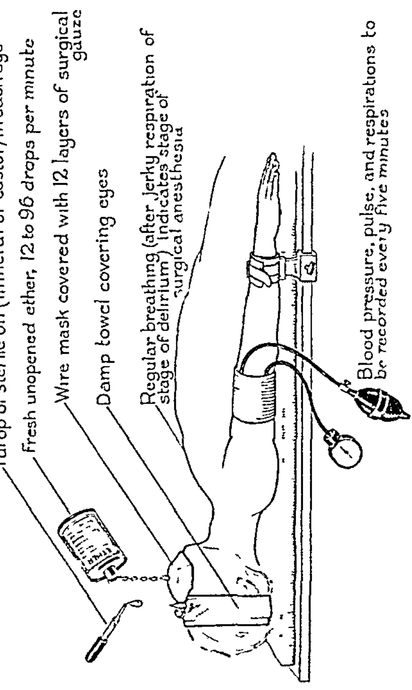


Fig 109 Technique of ether anesthesia

edges, so as to deliver the ether through a wick or gauze or cotton placed in one of the grooves

The following paragraph apropos the *rate of administration* of ether is quoted from Goodman and Gilman

> The rate at which the ether is dropped varies with the size of the drop and the thickness of the mask, it is usually 12 drops during the first minute, 24 during the second, 48 during the third and 96 during the fourth By this time the ordinary mask is saturated and the concentration of ether under the mask has approached 10 volumes per cent Also by this time, the patient is in the second or excitement stage of anesthesia The rate of approximately 100 drops per minute is continued for about 15 minutes During this interval, the concentration of ether under the mask is much higher than is later needed to maintain the desired depth of anesthesia The reason for this procedure is that the brain attains a given saturation with ether in a shorter period of time than do the other tissues which then act as a huge buffer system withdrawing anesthetic from the brain until all the tissues obtain their quota In the ordinary anesthetization of an adult one must therefore keep the mask completely saturated for approximately 10 to 15 minutes The rate of administration of ether is then slowly decreased so that the average rate during the second 15 minutes of anesthesia is approximately 50 drops per minute During this time equilibrium is being reached, a process probably requiring between 30 and 45 minutes The rate during the third 15 minutes is approximately 20 to 30 drops per minute For the fourth 15 minute interval and the subsequent period of anesthesia, the rate of administration is kept at a maintenance level of approximately 12 to 24 drops per minute The concentration of ether in the mask during this maintenance period is between three and five volumes per cent *

This technique is intended to suggest the procedure in an average case only, and must be subject to variations to conform to the needs of different individuals

* Goodman, Louis and Gilman, Alfred The Pharmacological Basis of Therapeutics 1941, p 52 By permission of The Macmillan Company, publishers.

For the treatment of fractures the first plane of surgical anesthesia is the one of choice The patient is carried through the stage of analgesia and the stage of delirium before he reaches the stage of surgical anesthesia The latter is recognized by a return of regular respirations (in contrast to the irregular or jerky respiratory movements in the stage of delirium), by a lessening of eyeball movements, and by a return to normal of the rapid pulse and elevated blood pressure of the stage of delirium Lightening of the anesthesia once the first surgical plane has been reached is indicated by irregular breathing, appearance of the swallowing or vomiting reflex, and an increase in the movements of the eyeball Deepening of the anesthesia is recognized by fixation of the eyeballs (freedom from movement), or by an increase in abdominal breathing resulting from beginning paralysis of the intercostal muscles *Either of these signs is the signal for lessening the anesthesia to* the first plane as described above

After care

Following ether anesthesia the patient's gown should be changed (if damp from perspiration) and he should be under constant supervision until the postanesthetic vomiting has stopped and he responds to questions or instructions

Supplementation —Ether anesthesia does not require supplementary measures

CHAPTER XXIV

ROENTGENOLOGIC STUDY OF FRACTURE HEALING AND BONE REACTION ADJACENT TO METALLIC PINS USED IN EXTERNAL FIXATION

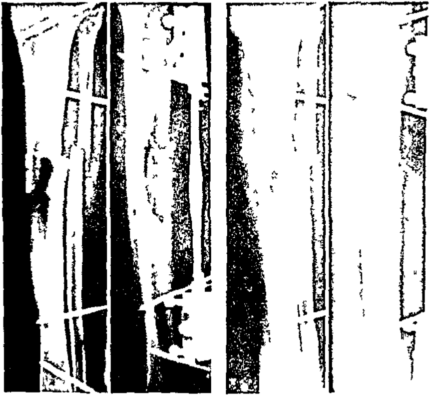
Lieutenant Commander Stephen L. Casper, MC-V(S), U.S.N.R.

It is beyond the scope of this brief chapter to discuss the various roentgenologic problems incident to the diagnosis and treatment of fractures. On the contrary, the limited field suggested by the title is to be closely adhered to, thereby enabling the reader quickly to compare the results of external fixation with metallic pins and those of other methods of fracture treatment. The material utilized for this study was selected without bias and is representative of the various conditions depicted. It is intended that this shall be an objective presentation, but the writer has not hesitated to interpret and compare his observations where this seemed indicated.

From the viewpoint of the roentgenologist, the use of external fixation by means of the Stader apparatus is superior to all other methods, for it has greatly reduced the need for portable x-ray examinations, it has reduced the number of roentgen examinations per case, and the films are of better diagnostic quality. The improvement in the quality of the films is attributable to the following circumstances: (1) The patients being ambulatory, most of the examinations are made in the x-ray department. (2) Relatively little difficulty is experienced in obtaining unobstructed anteroposterior, lateral and oblique views of the fracture site. (3) As the concurrent use of plaster casts is only occasionally required, better visualization of the bony architecture prevails.

Aside from these considerations that directly concern the roentgenologist, the writer would be remiss if mention were

omitted of the amazing stability imparted to the fracture fragments by this apparatus Routine comparative exami-



A B

FIG 110—Fracture of the tibia, the fragments of which were originally immobilized by means of a Lane plate When first seen by our service, osteomyelitis had developed around the screws, necessitating removal of the Lane plate and extensive saucerization of the infected bone fragments which were then immobilized by means of the Stader splint. *A*, Appearance of the fragments immediately following application of external fixation Note that the apposing fracture surfaces are merely thin cortical shells and mechanically unstable for fixation purposes. *B*, Appearance of the tibia two months later Not only is satisfactory bony union taking place, but the position of the fragments is unchanged Observe the absence of either pin reaction or demineralization following two months' immobilization

nations of fractured bones immobilized by the Stader splint disclose a *fixed relationship of the fracture fragments, regardless of the type of fracture* This rigidity of the frag-

ments prevails even despite a mechanically unfavorable configuration of the fracture surfaces (Fig 110) From the impartial viewpoint of the radiologist who all too vividly recalls the appearance of fractures treated by older methods orthopedic surgery as exemplified by this apparatus has indeed made great strides forward

PIN REACTIONS

As the insertion of metallic pins into the bone fragments is essential to the treatment of fractures by means of external fixation it is not inappropriate to consider the osseous reaction to these foreign bodies particularly as some physicians have criticized this form of fixation This criticism or distrust seems to arise from the necessity of using two metallic pins in each of the fragments to be immobilized Although it is admitted that the roentgenologist should not intrude or interpose his opinions in problems of surgical judgment, he nevertheless enjoys the unique opportunity of making impartial unbiased observations the summation of which seems to warrant valid conclusions pertinent to this problem

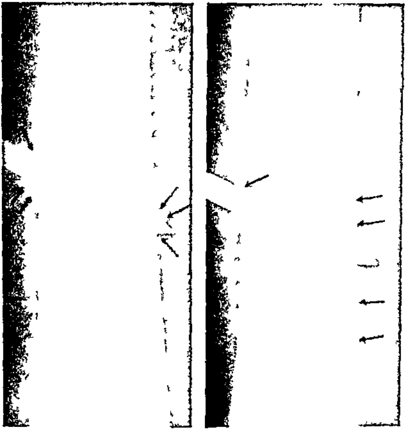
It has been deemed advisable to consider the subject of pin reaction under three subheadings (1) appearance of the bone immediately following the insertion of the pin, (2) bone reaction while the pin is in situ, (3) appearance of the bone following the removal of the pin

1 Appearance of the Bone Immediately Following the Insertion of the Pin

In most instances aside from the presence of the pin there is no change in the appearance of the bone

Occasionally, however, small collections of osseous material are noted in the soft tissues adjacent to the bone at the points of entrance and emergence of the pin This is undoubtedly calcareous material removed from the bone in the process of drilling in the pin and as such is of no clinical significance It is considered important however, that this occasional observation should not be misinterpreted as inflammatory pin reaction If it is made immediately follow

ing the insertion of the pin, such a deduction is obviously erroneous and unjustifiable On the other hand, if suitable films of the pin sites are not obtained within the first two



A B

Fig 111—*A*, Examination one day following insertion of pin showing presence of osseous particles adjacent to the points of its insertion and emergence *B* Re-examination two weeks after the insertion of the pin shown in *A* Observe the persistence of the calcareous material removed from the bone at the time of drilling In addition, *there is evidence of the normal or silent type of pin reaction as evidenced* by reactive type of periosteal thickening and minimal demineralization adjacent to the pin (see arrows)

weeks the origin of this osseous material will not be apparent and may be interpreted as inflammatory rather than mechanical (Fig 111)

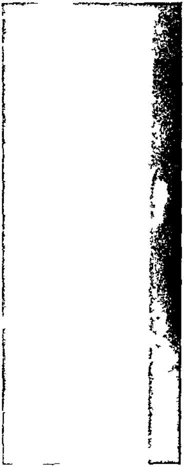


Fig 112

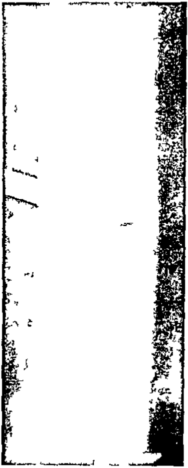


Fig 113

Fig 112.—Cortical fracture of femoral shaft produced by 'hammering in' an incompletely seated pin

Fig 113.—Unsatisfactory position of the pin due to its accidental partial withdrawal subsequent to satisfactory insertion of the pin in both cortices Note the pin track or 'dead space distal to the point of the pin, the extent of which corresponds to the amount of pin displacement.

In two instances there was a splintering of the cortex resulting from hammering in the pin following its incomplete seating into the distal cortex of the femoral shaft

(Fig 112) This may be anticipated in a large percentage of cases when a $\frac{7}{16}$-inch pin is driven through the distal cortex of the shaft of a tubular bone

Another occasional observation noted immediately following insertion of the pins is a "dead space" or pin track in the distal cortex beyond the point of the pin (Fig 113)

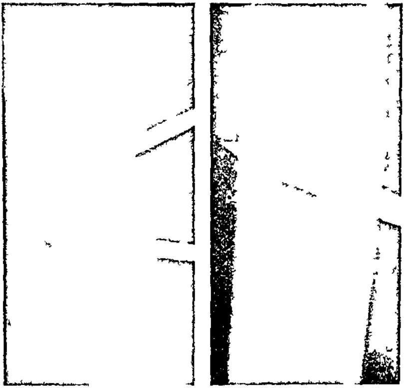


Fig 114.—Proper pin insertion Observe that the pins are firmly engaged in both cortices without excessive projection of the pin point into the soft tissues

This is the result of pin slippage prior to locking the pin in the pin block Although of no significance in any of our cases it is not devoid of potential danger, for the firm fixation of the pin in both cortices is essential to the satisfactory immobilization of the fragments

It is appropriate at this time to state the criteria by which one may judge whether or not the pins are properly placed

in the bones The correct insertion of the pin may be easily and accurately determined by noting whether it passes through the cortical portion of both margins of the bone (Fig 114) Although the projection of the pin into the soft tissues beyond the bone is unnecessary the point of the pin

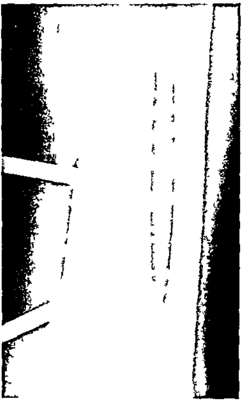


Fig 115 —Improper pin insertion Not only is there failure of pin fixation in both cortices but the more proximal pin passes through the fracture line

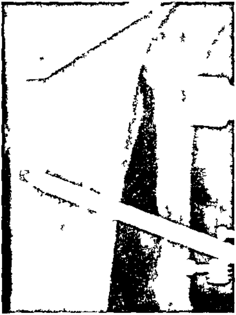
should not lie free in the medullary cavity, for, as was mentioned failure of firm fixation in both cortices permits undesirable motion of the pin in the bone, with resultant inadequate control of the fragments and localized bone reaction adjacent to the pin Furthermore, the selection of the

site of pin insertion should avoid the passage of the pin through the fracture line (Figs 113, 115)

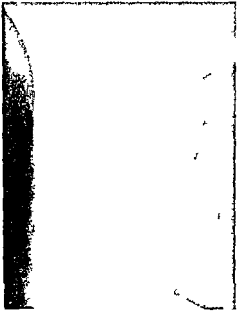
2 *Bone Reaction While the Pin Is in Situ*

Ordinarily the pins are permitted to remain in situ from eight to sixteen weeks, the determining factors being the bone involved and the type of fracture sustained It may be categorically stated that with the present technique, pin reactions of clinical significance are not anticipated, and therefore the duration of fracture fragment immobilization is determined by the degree of bony union rather than expediency This confident attitude of the orthopedic surgeons is substantiated roentgenographically, for only rarely, probably in the neighborhood of 1 per cent of all present cases (Figs 110, 116, 117), does one observe a bone reaction of clinical significance This rather dogmatic statement however, should be interpreted in the light of a careful analysis *of the phraseology employed Attention is first directed to* the clause "of all present cases," for this serves to exclude those fractures treated prior to the establishment of the present technique The validity of this discrimination is *merited by the fact that originally the pins were inserted* by means of an electric drill, and in some cases, metallic rather than nonelectrolytic fiber pin blocks were used The other clause to which attention is directed is "pin reactions *of clinical significance" With these reservations in mind* we wish to reiterate that clinically significant pin reactions are rare

Mild or Silent Pin Reactions without Clinical Significance —In about 75 per cent of the cases there is evidence of a mild or silent type of pin reaction that is only apparent roentgenographically This reaction, which is seen in from two to eight weeks following the insertion of the pins is regarded as a normal tissue *response to the trauma and* irritation incident to the insertion and continued presence of the pins It is definitely not infectious in character It may be recognized by either of two roentgenologic manifestations, the first of which is *a localized periosteal reaction*, slight to moderate in degree, with subperiosteal bone



A



B

Fig 116—Demonstration of excellent tolerance of osseous tissue to metallic pins which have been in situ for five months In *B* note the minimal periosteal reaction at site of pin insertion

formation. This takes place adjacent to the pin, and is most frequently observed at the site of entrance (Figs. 118, 119). Although symptomless and inconsequential, the roentgenological manifestations of this periosteal reaction are not transient, but persist as subperiosteal areas of sclerosis associated with a slight irregularity in the outline of the bone.

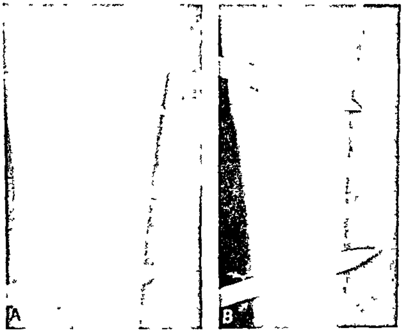


Fig. 117.—Excellent tolerance to metallic pins two and one half months following their insertion. In *B* observe the localized periosteal reaction (arrows) simulating calcareous material removed from bone incident to drilling.

In addition to this localized periostitis, there occurs in a *fewer number of cases a very narrow, almost imperceptible* radiolucent *zone of demineralization* adjacent to the surface of the pin (Figs 119, 120). This is most apparent in the medullary portion of the bone, but may be undetected even when present if the film is not of the best possible quality.

Obviously, therefore, these mild reactions should not be confused with those which were all too prevalent and neither

mute nor trivial when various dissimilar metals were rather indiscriminately placed in bone. These silent reactions are of most frequent occurrence in the more cancellous metaphyseal portions of the bones where they may become clin-

Fig 118.—Normal type of periosteal reaction approximately four weeks following pin insertion This type of proliferative reaction is more apparent on translucent roentgenographs.

ically evident through the medium of *pin seepage*. The latter condition, which is usually of short duration, tends to subside spontaneously, and if persistent should be regarded as abnormal. An investigation of this condition not uncommonly discloses one of the following etiologic factors: (1)

insertion of the pin into cancellous bone possessing a very thin cortex; (2) improper seating of the pin in the cortical portion of the bone, (3) insertion of the pin into demineralized bone; (4) insertion of the pin through traumatized devitalized, or an unusually thick layer of soft tissues, and (5) failure of electrical insulation of the pin It is there-

Fig 119—Normal bone absorption adjacent to metallic pins. This is best demonstrated by the translucent roentgenograph *A* Showing both bone absorption and periosteal reaction with subperiosteal bone formation The pin has been in situ for five months *B* Showing bone absorption adjacent to pin in situ for ten weeks

fore apparent that, although pin seepage is the clinician's problem, the radiologist is not absolved from participating in its solution insofar as the etiologic factor or factors may be apparent roentgenographically

It will be observed that no mention was made of osteomyelitis as one of the causes of pin seepage Although osteomyelitis is capable of producing this condition, its

omission was not an oversight, for in our experience the use of pins was not complicated by this serious and unfortunate infection This is of even greater significance when it is realized that external fixation was utilized in the treat

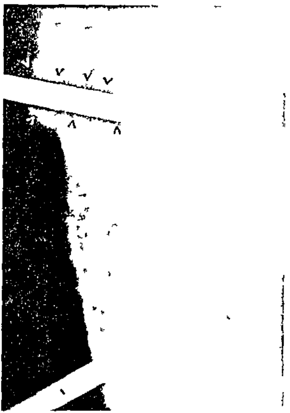


FIG 120 —Normal osseous absorption and localized periosteal proliferation in cancellous bone, pins in situ twelve weeks Compare with the more distal pin, which is devoid of reactive bone change

ment of certain fractures in which osteomyelitis was already evident prior to the insertion of the pins (Fig 121).

Pin Reactions of Clinical Importance—1 *Osseous Rarefaction.*—When pin reactions of clinical significance occur, they are manifested on the x-ray film by an obvious irregular zone of osseous rarefaction which extends from 3 to 10

mm. from the pin surface. This involves both the cortical and medullary portions of the bone, particularly the latter (Fig. 122). These osseous reactions are most pronounced in the cancellous portions of the bone, which are repeatedly traumatized by pin motion secondary to instability of the

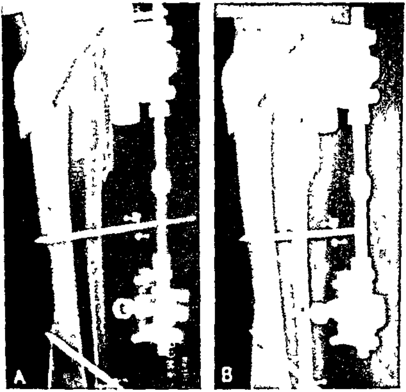


Fig 121.—Tolerance of osseous tissue to metallic pins in the presence of chronic osteomyelitis. The time interval between films *A* and *B* is nine weeks. The pins do not pass through the infected bone, the osseous defect noted between the two distal pins being the site from which a bone graft was removed

pin in the thin layer of surrounding cortex. We are also of the opinion that the periosteal phase of pin reactions increases directly with the thickness of the surrounding muscle tissue through which the pin passes. For this reason, it is more prevalent when pins are inserted into the thigh, elbow region and upper portion of the arm (Fig. 123). In

contradistinction to osteomyelitis the bone does not acquire the mottled or spotty type of demineralization so characteristic of this infection In all the cases of our series exhibiting this more extensive type of reaction the cause was directly attributable to either faulty insertion of the pin, cancellous or demineralized bone or electrolytic action between the pins The latter factor is deserving of careful

Fig 122—Abnormal pin reaction manifested by excessive periosteal proliferation and localized demineralization This was associated with a significant amount of protracted pin seepage

consideration not only because of its significance but also because it is preventable

2 *Reactions Due to Electrolytic Action between Pins*—The explanation of electrolytic action between metals placed in the body may be briefly summarized by stating that the tissue fluids act as an electrolyte when dissimilar metals are placed in the tissues This results in the formation of a bat

tery, the amount of current being proportional to: (1) the difference of metallic potential; (2) the degree in which they are acted upon by the given electrolyte (tissue fluids); and (3) the distance between the poles. These metals behave ad seriatim in accordance with Volta's law of the electro-

Fig. 123—Excessive pin reaction not infrequently observed in fleshy portions of the extremities, especially the region of the hip. Note the relative absence of reaction adjacent to the more distal pin

motive force of metals, and when different metals are connected or coupled directly, there is a *galvanic action* between the poles. It follows, therefore, that the tissue mass *around the metal, which at one time was described as* "necrotic tissue," is actually a deposit of ions exactly like

the deposit on a battery plate The reaction against it leads to the excessive proliferation of fibrous tissue which is protective, and the inhibition of bone growth, which is destructive. If a nonelectrolytic alloy is used, no ionization occurs and decalcification is no longer observed.

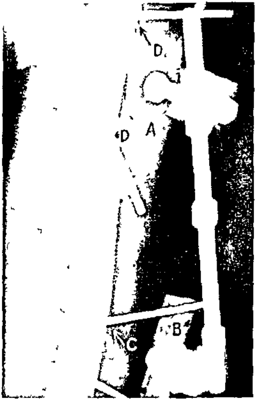


Fig 124.—Electrolytic bone reaction (*C*) adjacent to a pin immobilized in a metallic pin block (*B*). Note the absence of bone reaction adjacent to the two upper pins (*D*) immobilized in a fiber, nonelectrolytic pin block (*A*).

Although only pure metals and nonelectrolytic alloys are inert, their physical properties are unsuitable for use as bone pins for external fixation. It was therefore necessary to select a metallic substitute, the choice being a stainless steel alloy of very low carbon content, capable of receiving and retaining a

temper at the point of the pin As originally used, these stainless steel pins were locked in a metallic pin block by means of steel screws or bolts, the composite assembly constituting a galvanic couple with completion of the circuit by the electrolytic tissue fluids The bone reactions attendant upon the use of this apparatus substantiated the above hypothesis and necessitated a modification of the equipment (Fig 124) This modification consisted of replacing the metallic pin blocks with nonelectrolytic fiber blocks, and of course continuing the use of pins of identical chemical composition As a precaution against possible chemical variation, pins made from different pourings or batches of alloys are not simultaneously used in the same case In other words the pins used in any one Stader unit are "matched pins," in that they were all made from the identical pouring of molten stainless steel alloy From all practical considerations, this has completely eliminated electrolytic action between the pins

Carefully conducted experiments by a nationally renowned physicist have demonstrated that approximately 99 per cent of the potential electrolytic current is eliminated by the proper use of fiber pin blocks The residual 1 per cent current is generated along the pin surface by the galvanic action between the component elements of the stainless steel alloy from which the pin is made Incidentally, this phenomenon may contribute to that phase of the silent bone reaction previously described as "an almost imperceptible radiolucent zone of demineralization adjacent to the surface of the pin" Needless to say, the use of any electrolytic topical application or dressing to the skin surface between the pins is contraindicated

3 *Reactions Due to Faulty Insertion of Pins*—Faulty or improper seating of the pin is another important factor conducive to abnormal bone reaction Even though complying with the aforesaid roentgenologic criteria for satisfactory insertion of the pin errors may be committed during its insertion For example, unsteady or wavering pressure on the drill during the pin insertion results in a loose-fit of the pin in the bone Although this condition may not be directly apparent on the x-ray film its possible presence is suspected

if there is an otherwise unexplainable excessive amount of localized bone reaction at the site of pin insertion This is particularly true in the less fleshy portions of the extremities where pin reaction is normally absent or minimal

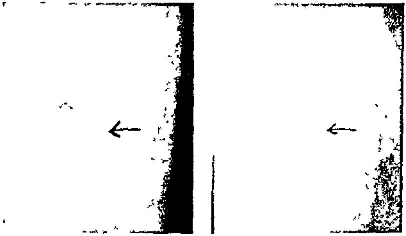
4 *Thermal Necrosis Following Use of the Electric Bone Drill*—In our experience the greatest single factor or agent responsible for excessive bone reaction was the use of the

A B

Fig 125—Ring sequestra *A* Axial projection *B* oblique projection The sequestrum in *A* was associated with pin seepage that in *B* was of the latent or silent variety and has been partially extruded from the bone Note the periosteal reaction in both *A* and *B*

electric bone drill So constant was this observation that not infrequently the roentgenologist without clinical knowledge of the case could unerringly designate those pins that had been inserted with the electric drill In cases such as these a radiolucent zone from 3 to 8 mm in diameter would appear around the pin within two or three weeks to be not infrequently followed after six to ten weeks by the presence of a small cortical or subcortical ring sequestrum (Fig 125)

Although occasionally latent, ring sequestra tend to perpetuate pin seepage, and are therefore surgically removed Ring sequestra have been observed that appear to be undergoing slow absorption (Fig. 126). We are of the opinion that both the ring sequestra as well as the antecedent demineralization are the result of thermal necrosis of bone due to either too rapid insertion of the pin or the use of a dull pin. If either infection or osteomyelitis should occur, it is felt that it should be regarded as an independent coexistent condition. This problem has not presented itself in any of



A B

Fig. 126.—Partial absorption of ring sequestrum. Time interval between films *A* and *B*—seven and one-quarter months.

our cases. In several cases that exhibited an abnormal pin reaction, a periosteal cuff was observed to project along the pin track into the soft tissues toward the skin surface. The *impression has been gained that this condition was particularly* prone to occur in conjunction with electrolytic reactions (Fig. 127).

While on the subject of thermal necrosis of bone, we wish to discuss briefly a most interesting case that came to our attention some time ago This was a white male, fifty-three years of age, who presented himself for treatment of an old ununited fracture involving the proximal third of the left

ulna Following apparently successful insertion of a bone graft, the fragments were immobilized by means of external fixation, and the case pursued an uneventful course for eight weeks At that time, because of an independent systemic disorder the patient received a hypertherm treatment, his temperature rising to over 105° F for a period of four

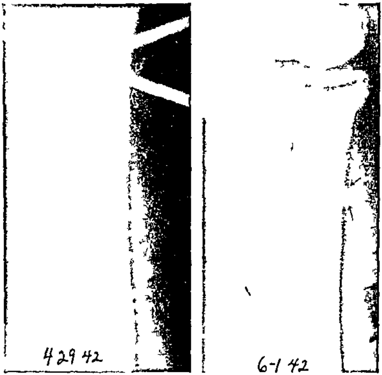


Fig 127—Appearance of periosteal cuff before and after removal of metallic pin.

hours On the following day all four of the pins became loose and the splint was therefore removed Serial roentgenographic studies revealed a rapidly progressive, fairly well defined destruction of bone adjacent to the pins, associated with a moderate degree of localized periostitis (Fig 128) This necrotic process was chiefly confined to the cortical portion of the bone and soon became stabilized, the

maximum diameter of the osteolytic area being 12 mm. At *no time was there any evidence of osteomyelitis. Aside from* its interest as an unusual complication, this case serves to emphasize the dictum that individuals with metallic foreign

Fig. 128—Thermal necrosis of ulna, approximately five months after a single hypertherm treatment. Note the sharply demarcated zones of bone destruction and extensive periosteal reaction with subperiosteal bone formation.

bodies embedded within their tissues, particularly the skeletal system, should not be subjected to either hypertherm or diathermy treatments.

3. Appearance of the Bone after Removal of the Pin

In the average case which was unattended by any significant bone or pin reaction, the removal of the pin imparts a definite sensation of firm fixation of the pin in the bone. If the bone is now examined roentgenographically, a well defined radiolucent channel or track is seen to mark the *former site of pin insertion. This is apparent when viewed*

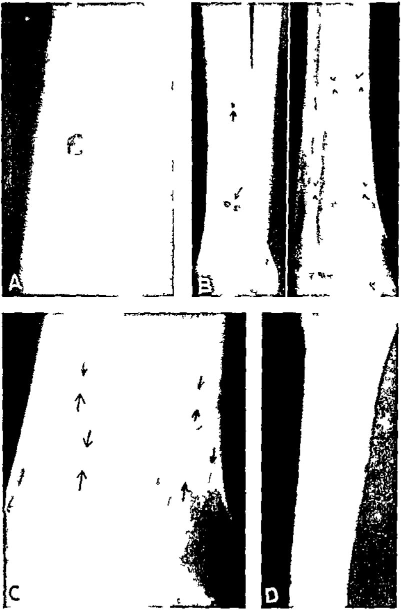


Fig 129—Normal pin holes immediately after removal of pins *A* Axial projection *B* oblique and profile projections of pin holes *C D* profile projections showing difference between cortical and medullary portions of the pin tracks

both axially and in profile. When observed in the axial projection, the channel presents a circular defect corresponding to the cross section of the pin around which this track formed. In profile, the channel appears as two thin parallel lines of increased density separated by a radiolucent zone of slightly lesser density than that of the surrounding

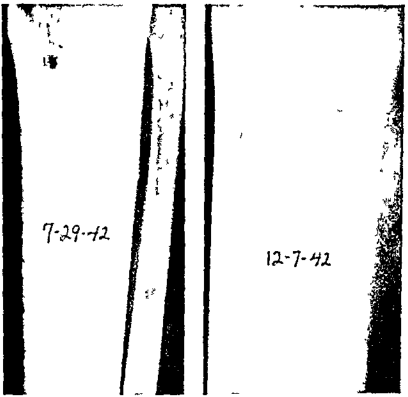


FIG 130.—Comparative examination of pin holes, demonstrating the insignificant change taking place in four and one half months.

medullary cavity of the bone. This channel is most evident in the medulla, the diameter of the radiolucent zone naturally corresponding to that of the pin. If viewed obliquely, this shadow is a combination of those seen in the axial and profile projections, the cortical defects being particularly well defined (FIG. 129). It is suspected that the segment of the pin track traversing the medullary portion of the bone

is sealed off from the marrow cavity by a thin circumscribed cylindrical zone of osteosclerosis

A representative number of pin channels have been studied by means of serial roentgenographs taken over a period of six months following removal of the pins The only change observed to date has been a partial loss of sharp definition in the outline of the channel This is usually best demonstrated in the profile projection (Fig 130) Although our investigation of this problem is at present incomplete it is suspected that these channels may persist for years and some may be permanent

HEALING OF FRACTURES

In our experience the healing of fractures that are reduced and immobilized by means of external fixation is as prompt and satisfactory as that observed when other types of fixation are employed only one of our cases resulting in nonunion There are however two types of fractures to which this generalization does not apply in one union is accelerated—in the other it is retarded The first of these is the *oblique* or *spiral* fracture involving the diaphyses of tubular bones In cases such as these it is found that firm bony union takes place in an appreciably shorter period of time than in similar fractures immobilized by other methods It is not improbable that this acceleration of union is dependent upon rigid immobilization of large fracture surfaces which permits uninterrupted organization and ossification of the extensive exudate and osteoid tissue found at the fracture site The other type of fracture the one in which union is delayed is the *transverse* variety involving the middle third of the tibial shaft It is suspected that the retarded union encountered in this type of fracture is attributable to rigid immobilization of the fragments by the Stader splint Whereas this quality is advantageous when large fracture surfaces are present it is of dubious value when the fracture is transverse and the blood supply none too abundant for under these circumstances the osteoid tissue is rather meager and if the fragments are rigidly immobilized there is an absence of stimulation of callus forma

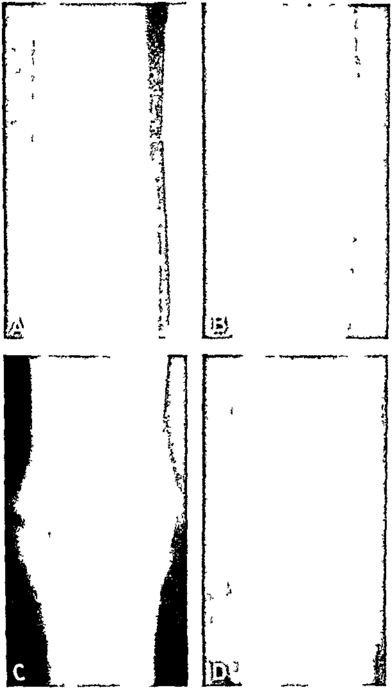


Fig 131.—Progressive healing of a transverse fracture involving the midportion of tibial shaft. *A*, Appearance of the fracture three weeks after the injury, *B* five weeks later, *C*, *D*, two and one half months later The figures *C*, which is an anteroposterior view, and *D*, an oblique projection of the fracture site, demonstrate the relatively small amount of external callus

tion that is usually engendered by the slight motion of the fracture surfaces permitted by other methods of fixation In order to overcome this disadvantage, it has been suggested that, following a relatively short period of external fixation of the fragments, sufficient to allow for the deposition of fibrous callus at the fracture site, the external fixation apparatus shall be replaced by a walking cast It would appear that a routine such as this would insure the advantages of both methods

Fig 132 —Absence of demineralization after seven weeks' immobilization by means of external fixation

In general, it has been observed in uncomminuted transverse and oblique fractures that the formation of external callus is not as abundant as when immobilization is accomplished by methods other than external fixation This is attributed to the excellent reduction and fixation of the fractures by the type of apparatus under consideration As this reduction in the amount of external callus has no effect upon the production of intermediate and internal callus, no concern need be engendered as to the healing process (Fig 131)

Post-traumatic demineralization or osteoporosis has not been conspicuous in fractures treated by external fixation, unless it is deemed necessary to maintain fixation through a joint We are of the opinion that the relative absence of demineralization may be ascribed to the freedom of joint motion permitted by the Stader splint (Figs 110, 132)

The criteria that we employ for satisfactory healing of fractures are those generally accepted by roentgenologists namely, (1) evidence of bony callus formation, (2) progressive indistinctness of the fracture line, and (3) return of normal bony architecture On the other hand, if the fracture lines tend to become more distinct, and particularly if the fractured ends of the bone acquire a slightly tapered or conical configuration, delayed union is anticipated

At the risk of appearing trite, we wish to emphasize that it is incumbent upon the roentgenologist to pay meticulous attention to the apposition of the fracture surfaces following reduction This is emphasized because, with this type of reduction and fixation apparatus, either excessive distraction or impaction of the fragments may be produced and if uncorrected, poor results will ensue

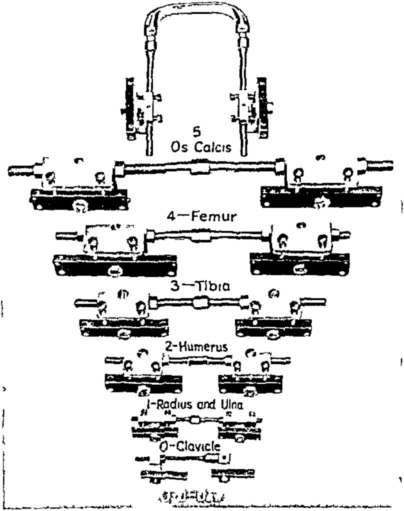


Fig 133.—Stader splints. All splints are of the same general design Lengths jaw (No 0 J), 4 inches, clavicle (No 0), 5 inches radius and ulna (No 1), 9 inches, humerus (No 2), 11 inches tibia (No 3), 13 inches, femur (No 4), 16 inches The os calcis splint (No 5) comprises two extension bars and pin blocks which permit two pins through and through in the lower portion of the tibia, one U shaped os calcis bar bringing the insertion of one pin through and through the os calcis The instrument is unassembled (In the illustration the number and name of each splint are inserted *below* that splint.)

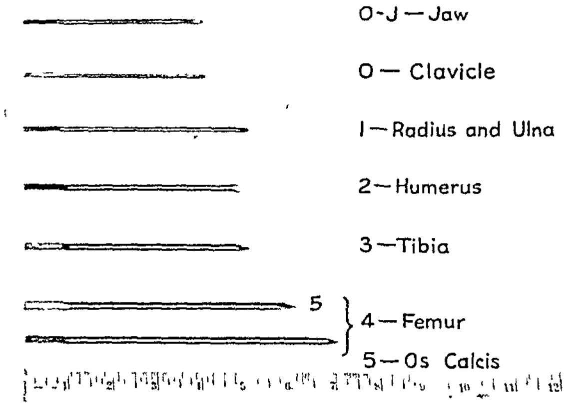


Fig. 114—Stainless steel pins One end is pointed like a trocar with three major sides and an additional special cutting edge The other end of the pin has a flat surface milled upon it for the purpose of fastening it into the flexible shaft drill during the pin's introduction Measurements Jaw (No 0-J), 4 inches long, 1/8 inch in diameter at shank with reduced diameter pin 3/8 to 1/2 inch long 1/16 inch in diameter, clavicle (No 0), 4 inches long, 3/32 inch in diameter, radius and ulna (No 1), 5 inches long 1/8 inch in diameter, humerus (No 2) 5 inches long, 5/32 inch in diameter, tibia (No 3), 5 inches long, 3/16 inch in diameter, femur (No 4), two lengths, 6 inches and 7 inches, both 3/16 inch in diameter, os calcis (No 5), 6 inches long, 3/16 inch in diameter (same as femoral pin)

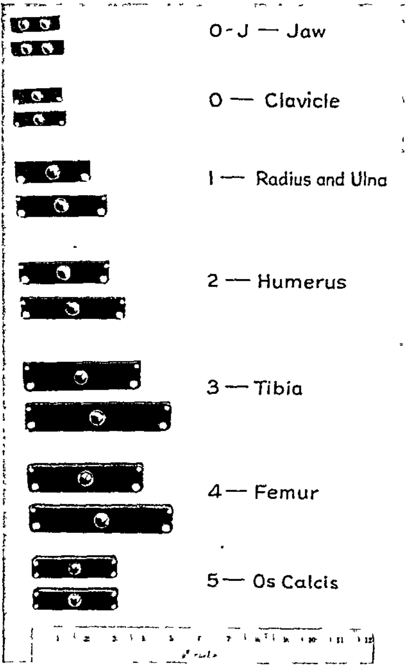

0-J — Jaw
0 — Clavicle
1 — Radius and Ulna
2 — Humerus
3 — Tibia
4 — Femur
5 — Os Calcis

Fig. 135.

Fig 135.—Pin bars. Pin bars are made of molded plastics with special metal inserts to prevent set screws from pulling out. The bars may be sterilized by boiling or autoclaving Measurements jaw (No 0-J), *two sizes, one $1\frac{5}{8}$ inches long, $\frac{1}{2}$ inch wide and $\frac{1}{4}$ inch thick* the other, $1\frac{1}{2}$ inches long, $\frac{1}{2}$ inch wide and $\frac{1}{4}$ inch thick, clavicle (No 0), two sizes, one $1\frac{5}{8}$ inches long, $\frac{1}{2}$ inch wide and $\frac{1}{4}$ inch thick the other, $1\frac{1}{2}$ inches long, $\frac{1}{2}$ inch wide and $\frac{1}{4}$ inch thick, radius and ulna (No 1), *two sizes, one $2\frac{1}{2}$ inches long, $\frac{3}{4}$ inch wide and $\frac{3}{8}$ inch* thick, the other, 2 inches long, $\frac{3}{4}$ inch wide and $\frac{3}{8}$ inch thick, humerus (No 2), two sizes, one 3 inches long, $\frac{3}{4}$ inch wide and $\frac{3}{4}$ inch thick, the other, $2\frac{1}{2}$ inches long with same width and thickness, tibia (No 3), specifications exactly the same as for femur splint and interchangeable with it, femur (No 4), two sizes, one 5 inches long, 1 inch wide and $\frac{3}{8}$ inch thick, the other, 4 inches long, 1 inch wide and $\frac{3}{8}$ inch thick *(may be used as above or two of the same size may be used)*; os calcis (No 5), 3 inches long, $\frac{3}{4}$ inch wide and $\frac{3}{8}$ inch thick

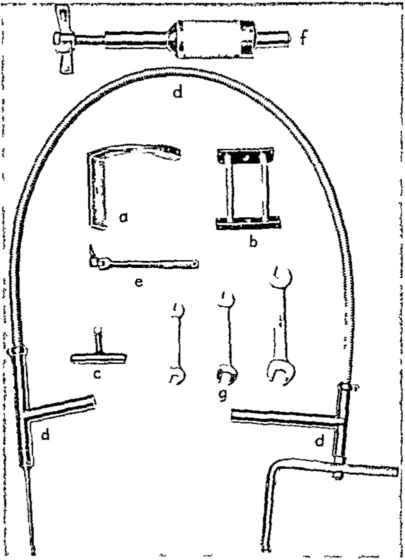


Fig 136

Fig 136.—Stader splint accessories a Right-angled pin bar for short fragments of the tibia require two 5 by 3/16 inch pins, and can be used on either the tibial or the femoral splint.

b, The projected pin bar used for the distal extremity of the humerus requires pins 5 inches long and 5/32 inch in diameter

c, The pin handle, T-shaped, with set screws for introducing pins by hand, but more commonly used for extracting pins

d Flexible shaft drill, hand-operated, 4 feet long Hard piece can be detached and sterilized separately Pins inserted into chuck and locked into place with set screw

e, Universal wrenches for activating set screws in pin bars etc. One large wrench, 6 inches long, is used on instruments 1, 2 3 4 and 5, and one small wrench, 5 inches long, is used on instruments *0* and *0-J* End wrenches two of each, with end openings of the following sizes 5/16 inch by 3/8 inch, 3/8 inch by 1/4 inch, and 1/4 inch by 3/8 inch.

f, Pin cutter, combination hydraulic and screw type, used for cutting excess pin when desirable (Should not be sterilized.) Jaws are of a cylindrical type largest hole for cutting off 3/16 inch and 5/32 inch pins, smallest hole for cutting off 1/8-inch and 3/32 inch pins (always have the threaded stem unscrewed completely so that poles in cutting area will be in apposition). When instrument is not in use, threaded stem should be retracted as far as possible

g Wrenches for activating adjusting screws, lock nuts and turn buckle

APPENDIX

CHAPTER XXV

TREATMENT OF FRACTURES AT SEA BY SKELETAL TRACTION

Traction and countertraction were used by Hippocrates in the treatment of fractures, and in the fourteenth century, Guy de Chauliac recognized the difficulties incident to the proper management of fractures of the femur He suspended fractures in a sling bandage and treated fractures of the femur by means of weight and pulley Ambroise Paré, in the sixteenth century, gave a splendid description of a similar method and referred to it as his pulley He also described the Glossocomium (a hoisting winch), the extension apparatus of the ancients Fabricius Hildanus (1560–1634) secured a pulley to the foot of the bed and suspended a jackstone to the heel for continuous traction The first cases on record in America in which the weight and pulley method was used were described by William C Daniell, of Savannah, Ga (1829), and L A Dugas, of Augusta, Ga (1854) In 1861 Gurdon Buck perfected this method of traction and extension and made a report of twenty one cases to the New York Academy of Medicine The strong approval given by two great contemporaries, Samuel D Gross and Lewis A Stimson, made this method at once recognized throughout the world To facilitate the use of weight and pulley for continuous traction and extension, various bed frames have been devised, the best known of which is the "Balkan frame"

Wijnen claims that Doctor Metz first used the frame in 1898 and described it in 1903 A Dutch ambulance unit brought it to Serbia, where it drew the attention of the

French and Americans and was adopted under the name of the Balkan frame

The Balkan frame was modified by Blake, Gasette Desfosses Charles-Robert, and Sinclair to answer any requirement in hospitals but not on hospital ships The vibration, rolling and pitching of a ship sets the extension weights attached to ice tongs Steinmann pins, and other apparatus for traction, into a pendulum motion which is very painful and annoying to the patients and frequently defeats the purpose for which the weights are applied

The problems encountered in the treatment of fracture at sea by skeletal traction prompted Shaar to devise an extension apparatus and fracture frame to overcome the pendulum motion transmitted from the traction weight to the fracture This apparatus was first used on the U S S *Mercy in 1927, later on the U S S Relief, and still later on* battleships and airplane carriers It may be used to equal advantage ashore

The frame has many advantages over the Balkan frame It is more compact, durable simple in construction and inexpensive and is easily adjustable to meet any requirements of skeletal traction It requires little space for storage when not in use and in a few minutes it may be clamped to any bed or bunk The Balkan frame, on the other hand, requires 71 feet of 1 by 1¾ inch lumber, 280 clamps screws, wing nuts, bolts, and so on This renders the Balkan *frame a fire hazard aboard ship and impractical to apply* to a bunk

CHAPTER XXVI

ANTIPENDULUM EXTENSION APPARATUS AND FRACTURE FRAME

Apparatus Devised to Overcome Handicaps Found in Use of Balkan Frame at Sea

The fracture frame is made of metal tubing, either of iron or brass (Fig 137), which may be clamped to any bed or bunk (Fig 140) Through the metal tubing multiple fenestrations are made sufficiently large to admit a strong steel rod

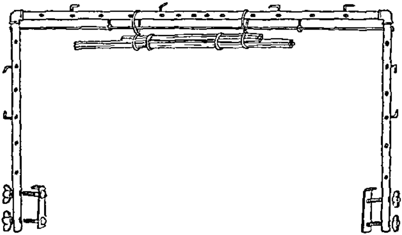


Fig 137.—The antipendulum extension apparatus and fracture frame requires small space for storage is easily and quickly assembled and may be clamped to any bed or bunk The clamps shown in this figure are for use on bunk in sick bay (Splint Manual U S Navy)

which may be secured by a thumbscrew at any desired length (Fig 138) The fenestrations are made in various directions so that any angle may be obtained To the metal rod a pulley with a swivel is clamped at the required distance

The antipendulum apparatus is an essential feature of the frame Two types are required, one for the traction weights and the other for weights suspended over the bed (Fig 139) The apparatus for traction consists of a square rod, the

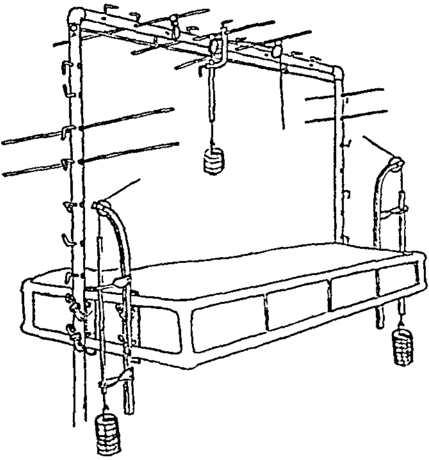


Fig 138 —The antipendulum extension apparatus and fracture frame when assembled and secured to a bunk in the sick bay (Splint Manual U S Navy)

upper end of which is curved to receive a pulley A suitable clamp is applied to its shaft by means of which it can be secured to a bedstead or bunk Immediately underneath the pulley is a small piece of metal tubing which is attached to the main rod by two small connecting rods It is so con

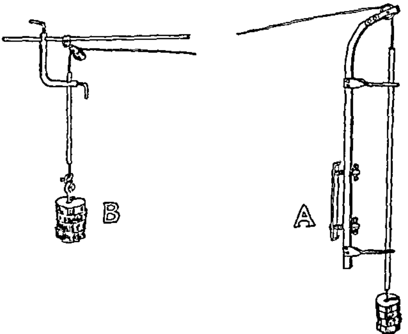


Fig 139.—The antipendulum apparatus *A*, For traction weights *B*, For weights suspended over bed. (Splint Manual, U. S. Navy.)

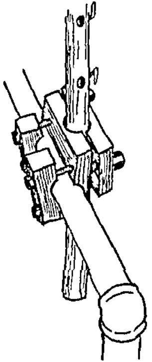


Fig 140.—Clamp to secure fracture frame to a bed or bunk.

structed that the traction cord upon leaving the pulley can be passed down through the metal tube in a perfectly straight line. The weight is attached to the cord immediately after it emerges from the tube.

The purpose of the tube is to keep the traction cord in a straight line and to prevent the weight from being set in

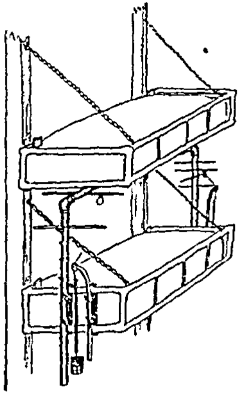


Fig 141.—The antipendulum extension apparatus and fracture frame, illustrating its use when double bunks are used The clamp is constructed in such a way that the frame may be elevated or lowered to any desired height. (Splint Manual, U. S Navy)

pendulum motion by the rolling and pitching of the ship at sea. A similar apparatus is secured to the other end of the bed for a traction and countertraction weight. The antipendulum apparatus used for weights suspended over the patient's bed consists of an L-shaped metal rod, with a fenestration through each end, one to secure the rod to the

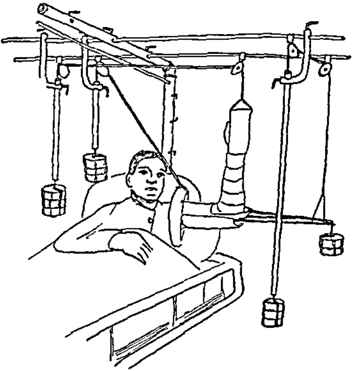


Fig 144—The antipendulum extension apparatus and fracture frame illustrating the method of applying and suspending the Thomas traction arm splint in fracture of the humerus (Splint Manual U S Navy)

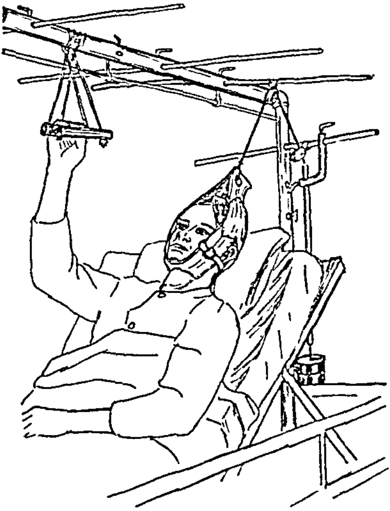


Fig 145.—The antipendulum extension apparatus and fracture frame, illustrating the method of applying traction to the head in *fractures and dislocations of the cervical vertebrae* (Splint Manual, U. S. Navy.)

CHAPTER XXVII

ADJUSTABLE HAMMOCK FOR TREATMENT OF FRACTURES OF THE PELVIS

The use of a sling or a hammock in suspending the injured pelvis has been acknowledged to be a useful and practical method The apparatus which is commonly used consists of a wooden bar attached to the full length of the hammock where main pull is applied To offset the lateral drag of the hammock which may cause an overlapping of fragments a wooden spreader is made, the width of which is that of the individual patient This necessitates the making of a new spreader every time the hammock is used in the treatment of a fractured pelvis

To prevent pendulum motion in the suspended pelvis by the rolling and pitching of a ship Shaar designed an adjustable hammock (Fig 146) which meets the necessary requirements irrespective of the size and width of the pelvis

The hammock consists of four metal rods and four thumb screws The two longitudinal rods are made to support the hammock and the cross rods pass through their extremities to act as stretchers The exact width of the patient is determined and the cross rods are secured in the proper position by means of thumb screws (Fig 147) The width can be adjusted to a fraction of a centimeter This eliminates the making of a new wooden spreader for every patient The firmness and stability of the adjustable hammock gives it additional advantage aboard hospital ships Also it may be secured to the bed or bunk (Fig 148) to prevent the pendulum motion

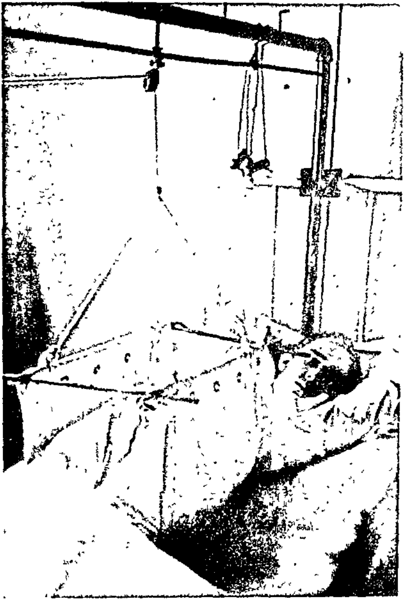


Fig. 146.—The suspended hammock.

Fig 147—The frame and hammock stretcher.

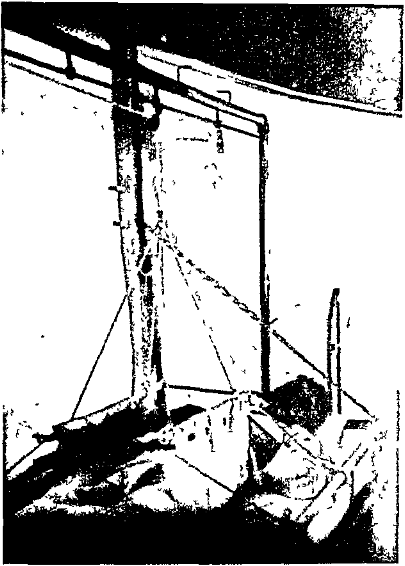


Fig 148 —The suspended hammock secured to the bunk to prevent the pendulum motion

BIBLIOGRAPHY

Albee Bone Graft Surgery in Disease, Injury and Deformity New York, Appleton Century Co, 1940

Anderson, R An Ambulatory Method of Treating Fractures of the Shaft of the Femur Surg, Gynec & Obst., *62* 865, 1936

Boever A Fixateur Externe, Nouveau Modele Le Scalpel *86* 1175, 1933

Bohler, L Apparate zum Einrichten vom Knochenbruchen unter Schraubenzug Munchen med Wchnschr, *75* 2047, 1928

Bohler, L. Die Technic der Knochenbruchbehandlung Maudrick, Wien, 1935

Bosworth D M Skeletal Distraction Surg, Gynec & Obst, *52* 893, 1931

Bradford, Charles H Mechanical Fixation of Fractures Proc Royal Soc. Med, *34* 786, 1941

Campbell Operative Orthopedics Mosby, 1939

Carter, R M Fixed Skeletal Traction in Fractures of the Leg J Bone & Joint Surg, *15* 737, 1933

Christie, H K. A Simple Appliance for the Correction of Gross Displacement in Tibial Fractures J Bone & Joint Surg, *23* 955 (Oct.) 1941

Codivilla A Means of Lengthening in Lower Limbs the Muscles and Tissues Which Are Shortened through Deformity Am J Orth Surg, *2* 353, 1904

Converse and Waknitz External Skeletal Fixation in Fractures of the Mandibular Angle. J Bone & Joint Surg, *24* (1) 54 (Jan) 1942

Cottle, G F Splint Manual, United States Navy United States Naval Medical Bulletin Volume, 29, No 4

Crile, Capt Dennis W, R A M C Fracture of the Femur—A Method of Holding the Fragments in Difficult Cases Brit J Surg *4* 458 1919

Desquin L Réduction et Contention des Fractures Oblique de la Jambe Ann de la Soc Medico-Chirurg d Anvers, 1907

Dubourg and Barroux Technique de Réduction et de Contention des Fractures Graves des Jambe par une quadruple Transfixation Tibiale *46* 126 (Jan) 1938

Freeman, Leonard The Application of Extension to Overlapping Fractures Especially of the Tibia, by Means of Bone Screws and a Turnbuckle without Open Reduction Ann Surg, *70* 231 1919

Goodman Louis and Gilman, Alfred The Pharmacological Basis of Therapeutics New York, The Macmillan Co, 1941

Goosens M J Nouveau Matérial Pour Osteosysthese, Le Fixateur Externe et Rotules Le Scalpel *85* 149, 1932

Griswold P A Double Pin Skeletal Fixation in Fractures of the Leg Surg, Gynec & Obst. *68* 573 (Feb 2 A) 1939

Hans Hans Kunstschwiele, Druchschutz und Firschiene drei Neuheiten in der Verbandtechnik Zentralbl f Chir, *4* 202, 1927

Haynes, Herbert H Treating Fractures by Skeletal Fixation of the Individual Bone South. Med J, *32* 720-724 1939
Houdard and Judet Valeur des Méthodes actuelles d ostéosynthèse par fixateur externe chez l adulte J de Chir., *44* 673, 1934
Humphrey, Capt. R E, R.A.M C The Treatment of Septic Gunshot Fractures of Long Bones by Means of a Steel Extension Apparatus The Practitioner, *98* 467 (May) 1917
Ivy, Robert H Fractures of the Jaw, 2nd ed Philadelphia Lea & Febiger, 1938
Lamare, Jean Paul Device Used in Osteosynthesis Unpublished
Lambotte, Albin Evaluation of Fractures Brit M J *2* 1530 1912
Chirurgie Operatoire des Fractures, 1913
Lemmon, William T A Method for Continuous Spinal Anesthesia Ann Surg, *111* 141-144 (Jan) 1940
Lundy, John S Clinical Anesthesia. Philadelphia W B Saunders Co, 1942
Magnuson Fractures 4th ed. Philadelphia, J B Lippincott Co 1942
Manual of Surgical Anatomy, Surgeon General of U S Army 1918
Moore, John Royal Femoral Shaft Fracture—Pin and Plaster Method Am J Surg, *49* 168 (March) 1938
Murray, Clay R An Improved Method in the Use of Steinmann Pins for Traction. Surg Clin North America *8*(5) 1099 (Oct.) 1928
Orr, H W The Treatment of Fractures by Skeletal Traction with Fixation in Plaster J A M A, *98* 947, 1932
Parkhill, Clayton A New Apparatus for the Fixation of Bones after Resection and in Fractures with a Tendency to Displacement Trans Am Surg Assoc, *15* 251, 1897
Putti, V. The Operative Lengthening of the Femur J A M A *77* 934 1921
Riedel, Gustav Haltelochplate fur schanz sche Schrauben Zentralbl f Chir, *57* 81, 1930
Robert, F An Ambulatory Distraction Splint for Leg Fractures British Med J, *2* 1051, 1932
Schanz, A Über die nach Schenkenhalsbruchen zuruckbleibenden Gest hrungen Deutsche med Wehnschr *57* 2000 1925
Schumm, Herman C The Schanz Osteotomy for Fracture of the Neck of the Femur J Bone & Joint Surg, *19* 955 1937
Scudder, C L The Treatment of Fractures, 11th ed Philadelphia W B Saunders Co, 1938
Shaar, C M Anti Pendulum Extension Apparatus and Fracture Frame United States Naval Medical Bulletin Vol 28, No. 4 1930
Shaar, C M and Kreuz, F P Treatment of Fractures and Bone and Joint Surgery with the Stader Reduction and Fixation Splint. Surg Clin North America *22*(6) 1537 (Dec) 1942
Shaar, C M and Kreuz, F P Treatment of Fractures of the Os Calcis Presentation of a New Method Surg Clin North America *23*(1) 291 (Feb) 1943
Shaar, C M, Kreuz F P and Jones D T Fractures of the Tibia and Fibula, Treatment with the Stader Reduction and Fixation Splint. Surg Clin North America *23*(2) 799 (April) 1943

Speed, Kellogg Plaster Imbedded Skeletal Traction Surg, Gynec & Obst., *51* 854 (Dec) 1930

Stader, Otto A Preliminary Announcement of a New Method of Treating Fractures North American Veterinarian, *18*(1) 37 (Jan) 1937

Stader, Otto Treating Fractures of Long Bones with the Reduction Splint, North American Veterinarian, *20*(1) 55 (Jan) 1939

Steinmann A Nail Extension for Fractures Zentralbl f Chir, *34* 938, 1907 Brit. Med J, *2* 1534 1912 Inter Clin, *4* 221, 1926

Swart, Howard A Fractures of the Tibia and Fibula with the Roger Anderson Splint South Med J, *33* 1081 (Oct.) 1940

Waldron, Carl W Fractures of the Mandible. Journal Lancet, *62*(6) (June) 1942

Waldron, Kazanjian, and Parker Skeletal Fixation in the Treatment of Fractures of Mandible J Oral Surg, *1* 59–83 (Jan) 1943

INDEX

Note Page numbers of illustrations are in *italic* type